UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE OUTLET WORKS OF ADAMINABY DAM FOR THE AUSTRALIAN SNOWY MOUNTAINS AUTHORITY

Hydraulic Laboratory Report No. 397

ENGINEERING LABORATORIES

OFFICE OF THE ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

September 9, 1954

CONTENTS

LIST OF FIGURES

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of the Assistant Commissioner and Chief Engineer
Engineering Laboratories
Denver, Colorado
September 9, 1954

Laboratory Report No. 397
Hydraulic Laboratory
Compiled by: J. C. Schuster
Checked and reviewed by: J. W. Ball and H. M. Martin

Subject: Hydraulic model studies of the outlet works of Adaminaby Dam for the Australian Snowy Mountains Authority.

PURPOSE OF STUDY

The objectives of this study were to investigate the flow conditions through the gate structure, tunnel, and stilling basin of the Adaminaby Dam outlet works for normal operation and for operation as a diversion structure.

CONCLUSIONS

Outlet Regulating Gate Structure

1. Cavitation would occur in the transition as proposed in the preliminary design from the tunnel to the 6- by 7.5-foot regulating gate flow passages because of the abruptness of the boundary curvature in the top and sides of the transition.

2. The use of a transition with a top boundary curvature of 3 radii (4.125, ~~10~~8.833, and 17.875 feet) and side curvature of a 42.75-foot radius will prevent cavitation-erosion of the regulating gate flow passages.

3. Flow conditions in the flow passages upstream of the 6- by 7.5-foot outlet regulating gates will be satisfactory for all outlet gate openings when the 9- by 20-foot emergency or diversion control gates are fully opened.

4. A 48.5-foot-long transition from a 25.5-foot-wide by 21-foot-high rectangle to a 25-foot horseshoe-shaped tunnel with a center wall 43.5 feet long and tapered in thickness from 10.5 to 1.5 feet in a downstream direction will satisfactorily direct the water from the outlet regulating gates to the tunnel.

5. The outlet works will discharge the design maximum flow of 11,900 cfs when the total head at the gates is 308 feet of water.

6. Flow conditions through the outlet works are best when the gates are operated at equal openings.

7. Prolonged operation of the 9- by 20-foot diversion control gates between openings of 6 feet and fully closed for emergency closure of the outlet works might cause cavitation damage to the 9- by 20-foot gates and 6- by 7.5-foot flow passages to the regulating gates.

8. The coefficient curve of Figure 6B may be used to obtain the capacity of the outlet works.

<u>Outlet Works Stilling Basin</u>

1. A chute floor having a profile with a 10-foot horizontal section and a trajectory of $X^2 = 562y$ produced the best flow conditions in a stilling basin of 265 feet overall length.

2. Two parallel walls in the chute, spaced approximately 5 feet each side of the stilling basin centerline, which begin approximately 46 feet downstream of the tunnel exit, and slope downward in a straight line to a height of 18.75 feet at the end of the stilling basin chute, will serve to guide and stabilize the flow as it enters the basin.

3. No cavitation damage will occur on the 5-foot 5-inch-wide by 8-foot 1-1/2-inch-high stilling basin baffle blocks when the upstream corners are formed by a 3-radii curve of 10, 21.25, and 42 inches, and the flow passages between the blocks converge in the downstream direction.

4. Two rows of baffle blocks with the 3-radii curved corners produce effective energy dissipation in the stilling basin when the first row of four blocks is located 27 feet downstream of the end of the chute and the blocks are spaced 5 feet 1 inch apart and 2 feet 6-1/2 inches from the training walls; and the second row of three blocks is located 8 feet downstream of the end of the first row on the center line of the flow passages between the upstream blocks.

5. At a discharge of 11,900 cfs small quantities of water from waves in the stilling basin may overtop the 49.5-foot high training walls, but the riprap protection of the backfill should prevent damage.

6. The dentated sill at the end of the stilling basin will prevent undue erosion at the end of the basin floor.

7. Protection of the stilling basin exit channel by 1/2-cubic-foot to 1/2-cubic-yard riprap will prevent serious erosion by eddies, but some erosion by wave action may occur on the slopes.

8. The stilling basin operation will be satisfactory for a discharge of 11,900 cfs with the tail water 5 feet below the computed normal elevation of 3466.5.

9. The curve of Figure 24B may be used to determine the minimum tail-water elevation required for satisfactory operation of outlet works stilling basin.

<u>Outlet Works Used as Diversion Structure</u>

1. Flow conditions in the final design diversion gate section, water passages, transition, and tunnel will be satisfactory for all discharges to the design maximum of 28,000 cfs.

2. Flow conditions in the diversion structure will be best when the discharge is controlled by equally opened gates.

3. The discharge through the stilling basin should be limited to 20,000 cfs if possible during diversion to minimize erosion of the backfill and exit channel by wave action.

4. The bottom stiffener plates of the 9- by 20-foot gate leaves should be perforated to prevent cavitation pressures on the stiffener plate surfaces for small gate openings (0 to 0.8 feet).

5. A wedge-shaped deflector 13-1/4 inches long and 3 inches thick at the upstream edge of the gate slot will deflect the water across the slot and give satisfactory pressures within the gate slot.

6. The corners at the downstream side of the gate slot and the flow surfaces immediately downstream were adequately protected by the 3-inch upstream deflector, the 1-1/2-inch outward offset of the corners from the conduit wall, and the taper of the downstream frame width from 9 feet 3 inches at the slot to 8 feet in a distance of 3 feet 10-1/4 inches.

7. The diversion gates will discharge approximately 31,000 cfs with a total head of 201 feet upstream of the gates.

8. The coefficient curve of Figure 33B may be used to determine the capacity of the 9- by 20-foot gates and conduits.

RECOMMENDATIONS

1. Release water from equally opened gates to obtain the best flow distribution and the best flow conditions in the outlet works structure.

2. After the 6- by 7-1/2-foot regulating gates are installed; do not operate the 9- by 20-foot slide gates at partial openings for extended periods, particularly at openings between 6 feet and fully closed.

3. Release water from equally opened gates whenever possible when the outlet works is used as a diversion structure.

4. When possible, limit the maximum diversion discharge to approximately 20,000 cfs to prevent damage downstream of the stilling basin by eddy currents and wave action.

ACKNOWLEDGMENT

The hydraulic features of the Adaminaby outlet works were designed through the cooperation of engineers of the Australian Government, and engineers of the Dams, Mechanical, and Hydraulic Laboratory Branches of the Commissioner's Office, Bureau of Reclamation, Denver, Colorado, USA.

INTRODUCTION

The Eucumbene-Tumut Project, located in the Snowy Mountains area of southeastern Australia (Figure 1) is under the Snowy Mountains Hydro-Electric Authority which has established its headquarters at Cooma near the site of construction, approximately 260 miles southwest of Sidney. The reservoir at Adaminaby Dam, about 25 miles northwest of Cooma, stores water from the Eucumbene River and from the Tumut and Happy Jacks Rivers by flow through the Eucumbene-Tumut Tunnel Junction Shaft. When there is insufficient water in the Tumut River for power and irrigation, supplemental water is released to Tumut Pond from the Adaminaby Reservoir through the Eucumbene-Tumut Tunnel.

An outlet works through the right abutment of the dam provides a means for routing floods through the Adaminaby reservoir and for the diversion of flood waters during construction of the dam. Hydraulic model studies were made of this structure to assure that it would serve the two purposes.

The outlet works consists of a trashrack structure, approximately 1,350 feet of 35-foot diameter tunnel, a gate structure, 915 feet of 25-foot horseshoe tunnel, and a stilling basin 265 feet long (Figure 2). During construction of the dam, two 9-foot-wide by 20-foot-high slide gates at Station 22+15 will control releases from the reservoir. As construction of the dam nears completion, the large gates will be closed while two 6- by 7.5-foot high-pressure slide gates are installed in a block out a short distance downstream. After these gates are in place, they will serve to regulate water releases from the reservoir, and the 9- by 20-foot slide gates will be used only for emergency closure of the outlet works. **Figure 3**

Water from the upstream tunnel section flows through the gates into the downstream tunnel section, down a parabolic chute 148 feet long with a fall of 34 feet and into a 42-foot-wide stilling basin (Figure 4). Two walls approximately 102 feet long which vary in height from 0 to 18.75 feet and terminate at the junction of the basin floor and chute divide the chute into three flow channels. These walls are parallel and 5.375 feet each side of the basin center line.

Eight chute blocks 2.5 feet wide by 2.5 feet high are located at the junction of the chute and stilling basin floor. The stilling basin contains seven baffle blocks 5.4 feet wide, 8 feet long, and 8 feet high in two rows located 27 and 43 feet downstream of the chute blocks, and a dentated sill 8 feet high at the basin exit. The stilling basin walls are 49.5 feet high above the floor and provide a freeboard of approximately 7.5 feet above the computed normal tailwater elevation for an outlet works discharge of 11,900 cfs. A riprap blanket extending approximately 175 feet downstream of the basin exit will protect the exit channel from erosion.

INVESTIGATION

Outlet Works

Description of model. A 1:30 scale hydraulic model of the gate structure, the horseshoe tunnel, the stilling basin, and a portion of the downstream exit channel of the outlet works was constructed (Figure 5A). Water was supplied to the model from a 12-inch centrifugal pump and measured by Venturi meters. The water from the laboratory supply line to the model flowed through an 8-inch gate valve, a 90° vaned elbow, and a 4-foot length of 8-inch pipe containing a 6-vane flow straightener. An expanding section from the 8-inch diameter pipe to the 10-inch diameter upstream of the gate section was used to attach the piping to the model.

The model gate structure was constructed in sections consisting of the upstream transition, the diversion or emergency gates and flow passages, the outlet regulating gates and flow passages, and the downstream tunnel transition (Figure 5B). The model flow passages below the emergency gates were interchangeable with the regulating gate structure (Figure 5C) to facilitate testing of the outlet and diversion schemes. Observation of the flow was possible through a transparent plastic section between one diversion gate and the corresponding regulating gate (Figure 7A). Flow conditions in the horseshoe tunnel downstream of the model gates were visible in plastic sections of the tunnel (Figure 5A).

The stilling basin was constructed of wood to facilitate modification. The training walls and stilling basin floor were fastened to a plyboard chute formed on wooden templates. This stilling basin unit was then fastened to the tail box containing an erodible bed material of sand (Figure 5A). A variable-crest weir at the end of the tail box was used to control the tail-water elevation. Dimensions and quantities referred to in the following discussion are for the prototype structure unless otherwise noted.

Initial observations. A concentration of high velocity water from the jets of the regulating gates passed through the transition below the gate structure to cause a nonuniform distribution of water in the tunnel. The water flowed from the tunnel exit through the stilling basin chute as a jet approximately equal to the 25-foot width of the tunnel. The unequal distribution of flow in the chute prevented effective energy dissipation in the stilling basin. This resulted in a surging of the water in the basin and the formation of large waves in the exit channel. These observations disclosed the major part of the hydraulic model investigation would be concerned with the stilling basin unless modification of the gate structure and tunnel could produce an equal distribution of flow per foot of width in the stilling basin. Modifications of the gate structure and tunnel were studied to determine the feasibility of improving conditions upstream of the stilling basin.

The Gate Structure and Tunnel

Preliminary entrance to the 6- by 7.5-foot regulating gate flow passages (elliptical contractions). Water flowed from the fully open diversion gates through transitions to the regulating gate flow passages. The bottoms of the flow passages were horizontal and continuous with the bottom of the diversion flow passage. The top and two sides of the transitions were contracted by elliptical curves from rectangles 9.4 feet high by 7.9 feet wide to rectangles 7.5 feet high by 6.0 feet wide in a distance of 4 feet. The length of the regulating gate flow passages, including gates, was 37 feet (Figures 6A and 7A).

Piezometers were installed on the center line of the entrance to one transition, 20.75 feet above the floor of the conduit, in the top surface of the transition at the junction of the two elliptical curves; and in the top, bottom, and sides of the flow passage 18 feet downstream from the transition entrance (Figure 6A, preliminary design). The piezometers located 18 feet downstream from the entrance were used as a pressure reference and for calibration of the gates.

Pressures in the transition were satisfactory for discharges up to 5,300 cfs corresponding to a gate opening of 7.19 feet and a computed total head of 308 feet of water at the transition entrance. Pressures in the transition were subatmospheric for a discharge of 5,800 cfs with the gate fully opened 7.5 feet indicating that cavitation would occur at the junction of the top and side wall surfaces. The cavitation pressure extended from 1-foot downstream of the transition entrance to near the end of the transition section.

(Curve A, Figure 6A). The preliminary shape was unsatisfactory because of possible cavitation-erosion in the flow passages of the regulating gate structure.

Recommended entrance to the regulating gate flow passages (3-radii curve). Flow in the regulating gate flow passages approximated two-dimensional flow because of the relatively small 1.5-foot side contractions at the upstream ends. The elliptical side wall surfaces were replaced by side walls of 42 foot 9 inch radius that intersected the sides of the diversion flow passage at the transition entrance and were tangent to the sides of the outlet flow passage 11 feet 3 inches downstream of the entrance. The curvature of the top surface of the transition was changed to a 3-radii approximate ellipse with a semimajor axis of 11 feet 3 inches and a semiminor axis of 6 feet 7-1/4 inches (Figure 6A). These changes reduced the abruptness of the wall curvature and thus the tendency for flow separation.

Piezometers were located in the model transition at the junction of the top and side surfaces and at the center line of the top surfaces. Reference piezometers were placed 20.75 feet above the floor of the entrance and in the top, bottom and sides of the flow passage 18 feet downstream of the entrance, as in the preliminary design (Figure 6A). Pressures were satisfactory at all piezometer locations for a discharge of 5,950 cfs with the gate fully opened. Pressures at the junction of the top and side surfaces were approximately equal to those at the center line of the top surface (Curves B and C, Figure 6A). There was, however, a reduction in pressure at the top near the downstream end of the transition section. This was attributed to a higher local velocity at this point than that at the end of the section. An increased radius of curvature of the flow surfaces in this section would decrease the velocity and increase the pressure. No study was conducted to increase the radius because the subatmospheric pressure of approximately 1.5 feet of water at the surface was higher than a minus 15 feet allowable as a design criterion. The pressures and discharge capacity were satisfactory for the regulating gate structure.

Single gate discharge. Flow conditions in the transition downstream of the gate structure were satisfactory for single gate operation. The water was not uniformly distributed in the tunnel because of water ridges that formed near the downstream end of the transition. These ridges were reflected from side to side of the tunnel but did not cause serious concentration of the flow. The stilling basin effectively dissipated the energy of the 5,950 cfs discharge flowing from the tunnel (Figures 7B and C).

Flow from regulating gates (preliminary transition dividing wall, 43.5 feet long). Water from the regulating gates flowed through the transition into the horseshoe tunnel below the gate structure. The transition changed from a 25.5-foot-wide by 21-foot-high rectangle at the end of the gate structure to a 25-foot horseshoe-shaped tunnel 48.5 feet farther downstream. The jets from the two regulating gates were separated within this transition by a 43.5-foot-long wall on the transition center line. The wall, 10.5 feet thick for a distance of 7.0 feet downstream from the regulating gates, was tapered to a thickness of 1.5 feet in a distance of 36.5 feet (Figure 8, Wall A).

There was an uneven distribution of flow in the transition and tunnel. Water jets from the gates were confined at the outside and bottom by the transition but were unconfined at the inside and top. A 1.5-foot offset of the inside vertical wall at the end of the gate section (Figure 8) allowed the jets to diverge toward the center line of the transition. A longitudinal ridge of water formed in the center of the tunnel as the jets of water flowed together downstream from the end of the wall. Two ridges formed against the walls of the tunnel as the water was crowded toward the center line of the outlet works by the convergence of the transition. The water ridges combined at the center of the tunnel to form a single fin 17 feet high at a point 90 feet downstream of the end of the transition (Figure 9A). The flow through the tunnel was such that alternate peaks and troughs of diminished amplitude were formed at the center line. Near the exit portal of the tunnel the peak was predominate and a concentration of water occurred at the center of the stilling basin chute.

It was believed that flow conditions in the tunnel would be improved by an increase in the length of the transition and the center wall. An increase in the length of the transition, from the 48.5 feet of the preliminary design to approximately 145 feet was considered necessary to prevent the crowding of the water at the side walls. This change was not tested because the increased construction cost did not seem justified. Studies were made of the wall within the transition to determine if a change in its shape would improve flow conditions in the transition and tunnel.

Dividing wall 100 feet long and 13.5 feet thick. A wall 100 feet long and tapered from 13.5 feet thick at the end of the outlet gate structure to 1.5 feet thick at the downstream end was first tested (Wall B, Figure 8). The wall thickness was increased to 13.5 feet from the 10.5 feet of the preliminary design to prevent the divergence of the inside flow surfaces of the gate jets. A controlled divergence of the jet toward the center of the tunnel was accomplished, but the increased wall thickness at the end of the tunnel transition caused a reduction in the flow area and an increased depth at the side walls. The ridges at the tunnel walls were approximately 1.5 feet higher than in the preliminary design (Figure 9B). The ridge height in the tunnel downstream of the dividing wall was reduced, but there was no improvement in the unequal distribution of flow in the tunnel and the stilling basin chute.

Dividing wall 70 feet long and 13.5 feet thick. A dividing wall 13.5 feet thick for a distance of 25 feet and tapered to 1.5 feet in a distance of 45 feet or a total wall length of 70 feet was installed (Wall C, Figure 8). The height of the ridge downstream of the wall end was approximately 4 feet less than with the first wall. The depth of water at the sides of the tunnel was approximately equal for the two walls (Figure 9C). This wall did not improve the flow conditions in the tunnel and stilling basin.

As a result of the wall studies, it was concluded that no major improvement of the flow conditions in the tunnel and stilling basin could be obtained unless both the transition below the gates and the wall were modified. Although the flow pattern was undesirable from a hydraulic standpoint, it would cause no damage to the transition and tunnel. The preliminary transition and 43.5-foot-long wall were accepted for the outlet works.

Capacity of outlet works. The discharge capacity was determined for the outlet with the recommended flow passage entrance, the 48.5-foot-long tunnel transition, and the 43.5-foot long dividing wall. A maximum coefficient of discharge of 0.94 was obtained for the maximum gate opening of 7.5 feet (Figure 6B). The discharge capacity of 11,900 cfs for a total head of 308 feet of water at the entrance to the regulating gate structure was satisfactory.

The Stilling Basin

Preliminary chute floor profile with trajectory of $X^2 = 420y$. When water flows in a partly full curved bottom horseshoe-shaped tunnel, there is a natural concentration of water at the center and this concentration continues to some degree when the flow passes down a chute with a trajectory profile floor. Concentration of this nature at the outlet portal of the Adaminaby outlet tunnel was accentuated by the flow pattern in the transition below the gate structure. With the velocity of 95 feet per second at this point, the concentration continued through the chute and into the stilling basin causing a decrease in the effectiveness of the basin. It was believed that the basin action could be improved if the natural concentration caused by the curved bottom of the horseshoe tunnel could be reduced. A 50-foot-long transition from the curved bottom of the horseshoe section at the upstream end to a flat bottom at the chute entrance partially offset the concentration; but, the water did not spread to a uniform depth on the widening floor of the chute. The unequal distribution of discharge per foot of width of the basin resulted in extreme turbulence and waves overtopped the training walls. Since erosion of the downstream toe of the dam and the river channel adjacent to the stilling basin exit might result from such severe wave action, a modification of the stilling basin seemed essential.

A more gradual sloping of the chute floor to obtain additional spreading of the jet before it entered the basin was considered as a means of improving the stilling pool action.

Chute floor profile with trajectory $X^2 = 562y$. The trajectory profile for the chute floor was computed for a tunnel exit velocity of 95 feet per second. The horizontal length of the chute with this floor profile was 138.23 feet, approximately 20 feet longer than the preliminary chute, for the same 34-foot change of elevation between the tunnel invert and stilling basin floor. The origin of the trajectory of the chute floor profile was located 10 feet downstream of the tunnel exit (Figure 10). This horizontal section between the tunnel exit and the origin of the trajectory provided additional distance in which the concentrated tunnel flow could spread.

An improved distribution of the flow per foot of width of the basin was obtained, but a concentration of water still occurred along the center line of the basin (Figures 11A and B). The chute length was insufficient to force the water to spread to a uniform depth before it reached the basin.

Chute floor profile with trajectory of $X^2 = 695y$. A further increase in the length of the chute floor trajectory to 153.7 feet for a 34-foot change of elevation (Figure 10) did not materially reduce the water concentration. Severe turbulence and waves occurred in the basin and downstream of the basin exit and in the river channel (Figure 11C). Erosion of the training wall backfill and the river channel would result from waves that overtopped the walls or passed through the basin. This chute was unsatisfactory because the shortening of the stilling basin reduced its effectiveness.

The chute floor with the $X^2 = 562y$ profile was selected for further study because it produced the best overall flow conditions within the fixed combined length of 265 feet for the chute and stilling basin. The use of this chute, with properly sized and arranged chute and baffle blocks in the stilling basin, afforded a possible solution to the problem of obtaining effective dissipation of energy so the study was continued with this in mind.

Chute blocks. Small turbulent eddies dissipate energy more rapidly than large eddies and with less possibility of damage to a stilling structure so chute blocks were installed to induce smaller eddies. Four chute blocks, 3 feet high and 5 feet wide, spaced 5 feet apart with a 3.5-foot space between the end blocks and the training walls were placed at the end of the chute (Figure 10B). These blocks did not redistribute the chute flow sufficiently for effective energy dissipation. To obtain better distribution at the basin entrance the four blocks were replaced by eight smaller blocks. These blocks were 2.5 feet wide, 2.5 feet high, and spaced 2.5 feet apart (Figure 10C). The dimensions and spacing were based on data from studies previously made in the laboratory (Hydraulic Laboratory Report Hyd-380). The basin flow conditions were not improved noticeably because the water was still concentrated along the center line of the chute and there was little change in the turbulence.

Preliminary baffle blocks. The ineffectiveness of the chute blocks in improving the stilling basin action indicated the need for baffle blocks on the basin floor. Four 5.5 feet wide, 8.12 feet high, and 7.2 feet long blocks were located 27 feet downstream of the chute blocks with a 5-foot space between them and with a 2.5-foot space at the training walls (Figure 10D). General improvement in the effectiveness of the basin resulted from the use of the baffle blocks. Water concentration along the center line of the basin was dispersed by the blocks to increase the effectiveness of the basin. Waves were still present but there was a reduction in their height and less overtopping of the training walls occurred (Figure 12A). Improvement in the basin action was sufficient to recommend the use of baffle blocks, but more improvement was desirable.

The flow appeared to move from side to side in the stilling basin. Severe waves and turbulence occurred at the time the flow was concentrated along the training walls (Figure 12B). To obtain full benefit of the baffle blocks and to provide a satisfactory stilling action, it was necessary to stabilize the flow.

Chute dividing walls 34 feet high. Two walls were installed approximately 5 feet each side of the basin center line on the floor of the chute to stabilize the flow. These walls, with the tops horizontal, were approximately 138.2 feet long, were parallel to the chute center line, and were 34 feet high at the stilling basin entrance (Wall A, Figure 13A, and Figure 14A). Water flowing in the chute was guided by the walls in three separate jets to the stilling basin. The walls stabilized the jets and caused them to submerge and flow close to the floor of the stilling basin. The effectiveness of the stilling basin was increased because more of the water flowed against the chute floor and baffle blocks to give a more even distribution of the flow. The surface roughness was measurably reduced by the use of the walls (Figure 14B). Energy dissipation in the stilling basin was satisfactory but it was apparent that the length and height of the chute dividing walls could be reduced. However, before any tests were made to determine the optimum height for these walls, their alignment and spacing were studied.

A divergence of the dividing walls in the downstream direction to spread the jet caused the water to be deflected upward on the training wall sides of the walls. This resulted in a ridge of water higher than the top of the walls, less submergence of the jets, and a rougher stilling basin action. A convergence of the walls increased the concentration of water near the chute center line and resulted in a rougher basin action. Parallel walls proved to be the best arrangement. The space between the parallel walls could be varied from 8 to 12 feet with no visible change in the stability of the flow. A 10-foot spacing, 5 feet each side of the center line, was selected for the dividing walls on which the height was to be varied.

Chute dividing walls 12 feet high. The water depth at the front of the jump, approximately 84 feet downstream of the tunnel exit, varied from approximately 3 feet at the wall to 12 feet at the chute center line for the maximum discharge and normal tail water. The walls were made 12 feet high at the end of the chute with their tops sloped upward from this height to become tangent to the chute floor approximately 58 feet downstream of the tunnel exit, and were spaced 5 feet each side of the chute center line (Wall B, Figure 13A).

Operation of the model with these walls disclosed less effective energy dissipation than with the 34-foot high walls. The direction of the flow was not completely stable and the wave height was increased (Figure 14C). The energy dissipation was somewhat improved over that for the basin without walls (Figure 12) but the 12-foot walls were not considered to be of sufficient height.

Chute dividing walls 15 feet high. Walls 15 feet high and approximately 90 feet long (Wall C, Figure 13A) improved the effectiveness of energy dissipation over that for the 12-foot-high walls (Figure 14D). The water from the chute still did not submerge to flow along the floor of the stilling basin. The turbulent eddies were smaller than with the lower walls and there was less water overtopping the training walls. Further improvement in flow conditions was desirable so a higher wall was studied.

Chute dividing walls 18.75 feet high (recommended design). The wall height was further increased by increments of 15 inches until a height of 18.75 feet and a length of approximately 102 feet was represented on the model (Wall D, Figure 13A). Observations of the flow stability and basin turbulence for each of the three wall heights disclosed that the effectiveness of the energy dissipation with the 18.75-foot high walls was approximately equal to that for the stilling basin with 34-foot high walls. The other wall heights were less effective. The turbulence was essentially confined within the stilling basin and only a few waves were of sufficient height to overtop the training walls at the maximum discharge (Figure 15B and C).

An erosion test was made to determine the effectiveness of the stilling basin with the 18.75-foot walls, the 2.5-foot chute blocks, and the preliminary baffle blocks. The channel contours were formed in sand and covered with approximately one layer of crushed rock representing 1/2 cubic foot to 1/2 cubic yard riprap (Figure 16A). The model was operated for 8 hours 35 minutes (approximately 2 days prototype) at conditions representing a discharge of 11,900 cfs and a tail-water elevation of 3466.5. Erosion of the exit channel was not severe. Wave action and an eddy at the sloped right bank removed sand from beneath the riprap near the end of the cutoff wall. The sand was moved down the slope and deposited downstream of the stilling basin exit. A part of the riprap was carried down the slope but the most settled in place as the sand was removed (Figure 16B). The 18.75-foot high walls were adopted because they stabilized the chute flow and improved the stilling basin action, and because the erosion of the downstream channel was not severe. However, further study of the basin was desirable because of possible cavitation-damage to the preliminary baffle blocks.

Cavitation-erosion of baffle blocks. Cavitation-erosion has occurred on the concrete surfaces of stilling basin baffle blocks when they were not adequately streamlined in the direction of flow. The preliminary baffle blocks were rectangular in cross section and would require streamlining at the upstream corners to prevent damage by cavitation. Streamlined blocks are less effective energy dissipators than rectangular blocks because the head loss is less for streamlined flow contractions than for abrupt contractions. Therefore, a larger number of streamlined blocks than rectangular blocks are required to obtain comparable stilling action.

Baffle block with upstream corners streamlined to jet profile. Five baffle blocks 5 feet wide, 6 feet long, with streamlined upstream corners, spaced 3 feet apart and 2 feet from the training walls, were selected for study. The upstream corners of the blocks were shaped to the profile of a jet from a slot. The jet profile corresponded to a contraction of approximately 0.65. The contraction coefficient was based on the ratio of the 8 foot width between the block center lines and the 3 foot width of the flow passage between the blocks (Figure 13B).

A subatmospheric pressure of approximately 2.5 feet of water (model) occurred on the boundary near the upstream end of the model baffle block for the maximum discharge (Figure 13B). This pressure indicated that cavitation-damage would occur on the prototype. The curvature of the boundary was too abrupt and the blocks would be unsatisfactory.

Baffle blocks with beveled upstream corners. The upstream corners of the blocks were beveled to converge the 6-foot-long flow passage from a width of 4.62 feet at the entrance to 3 feet at the mid-point in an attempt to eliminate cavitation pressures. The beveled corner was intended to cause the flow between the blocks to separate from the surfaces at the upstream edges of the blocks and contract to the width of the space between blocks. A subatmospheric pressure of approximately 10 feet of water (prototype) occurred near the upstream corners of the blocks (Figure 13C). This indicated that the amount of bevel, or offset of the upstream edges from the sides of the blocks would be an important factor in obtaining satisfactory pressure conditions. Also, sharp corners would be necessary at the edges of the entrance to the flow passage. The installation of metal angles to preserve the upstream corners was not considered practical so additional tests were confined to streamlined shapes.

Baffle block with 3-radii curve at upstream edges--(recommended design). A baffle block with the upstream edges streamlined by a 3-radii curve (10, 21.25, and 42 inches) was next selected for study. The 10-inch radius of the 3-radii curve was tangent to the upstream face of the 65-inch-wide block 11.5 inches out from the center line. The 42-inch radius was tangent to the beveled side of the block 24 inches downstream and 27.5 inches out from the block center line. The flow passage between blocks was converged from a width of 46 inches at this tangent point to 36 inches at the downstream end of the 8-foot-long block (Figure 13D). The block length had been increased from 6 feet to 8 feet to increase the structural resistance to the overturning force of the water pressure on the 8.12-foot-high block. Pressures along the boundary were above atmospheric for the maximum discharge of 11,900 cfs and tail water elevation of 3456.5 feet (Figure 13D). The pressures on the blocks were satisfactory but five blocks (Figure 17A) did not seem to effectively dissipate the energy of the chute flow. A higher velocity of flow through the basin with the streamlined blocks caused a general decrease of the water surface elevation in the stilling basin. An increased wave action and turbulence extended downstream into the exit channel (Figures 17B and C). The shape of the baffle block was adopted because it was free of cavitation pressures, but further investigation was required to determine the proper arrangement of the blocks.

Arrangement using nine baffle blocks. Since the five streamlined blocks did not cause a head loss equal to that of the four preliminary blocks, a second row of four blocks was added 8 feet downstream and on the center line of the flow passages of the first row to increase the head loss (Figure 18A). An increased turbulence and wave action resulted because more of the flow from the chute was deflected over the blocks by the increased resistance. The effect on the flow was similar to that of a low wall placed across the basin at the position of the blocks. The stilling basin action was not satisfactory for this arrangement.

Arrangement using eight baffle blocks. A row of four blocks equally spaced across the width of the basin was placed 27 feet downstream of the chute blocks. A second row, 8 feet farther downstream, contained three blocks on the center lines of the flow passages of the upstream blocks and a half block at each training wall (Figure 18B). The resistance to flow was decreased by this arrangement and resulted in an improvement of the stilling action along the center of the basin. Water flowing between the training walls and the outside blocks of the first row was deflected upward by the half blocks in the second row. The waves caused by the upward deflection of the water overtopped the training walls to make the arrangement unsatisfactory.

Arrangement using seven baffle blocks (recommended design). The front row of blocks was spaced to reduce the quantity of water flowing between the training walls and the outside blocks. This increased the space between the 5-foot 5-inch-wide blocks to 5 feet 1 inch and decreased the space between the blocks and training walls to 2 feet 6-1/2 inches. The half blocks at the training walls in the second row were eliminated and three blocks were placed on the flow passage center lines of the first row (Figures 18C and 19A).

The effectiveness of the seven-block arrangement was comparable to that of the four preliminary blocks, but a smaller percentage of the waves that formed in the basin with the seven-block arrangement overtopped the walls. This occurred because of a generally lowered water surface caused by a slightly higher velocity of flow through the streamlined baffle blocks and the basin. The major difference between the two designs occurred at the basin exit where the turbulence and waves extended farther downstream with the seven-block arrangement (Figures 19B and C, and Figure 15).

An erosion test was made to compare the effectiveness of the arrangement of the seven streamlined blocks with that of the four preliminary blocks. The river channel was formed with sand and crushed rock was placed on the slopes and floor of the downstream channel to represent 1/2-cubic-yard to 1/2-cubic-foot riprap (Figure 16A).

Operation of the model for 8 hours and 35 minutes at a discharge representing 11,900 cfs caused an erosion at the right bank of the exit channel and a sand deposit downstream of the basin exit. Erosion by the eddy at the right bank was less extensive in the test with the streamlined blocks and resulted in a decreased sand deposit at the exit of the basin (Figure 20). In the eroded area, the sand and the rock had settled downward and shifted toward the basin exit. The deposition of material on the downstream slope of the dentated sill indicated there would be no undermining of the basin floor at the exit and that no material would be carried by the water over the sill into the basin. The riprapped slopes should adequately protect the basin cutoff walls and channel immediately downstream. The effectiveness of the energy dissipation was satisfactory, as evidenced by the erosion test. The stilling basin using seven baffle blocks was recommended (Figure 4).

Operating Characteristics of Recommended Outlet Works

General flow conditions. With the completion of the stilling basin investigation, the outlet works was considered hydraulically satisfactory. Further studies were made to record operational characteristics for both intermediate and maximum discharges. Flow conditions through the outlet works were satisfactory for the gates equally opened 25, 50, and 75 percent of full open at maximum design head. Discharges for these gate openings were, respectively, 2,250, 4,640, and 7,660 cfs (Figures 21, 22, and 23).

Flow in tunnel. The ridges of water originating in the recommended downstream tunnel transition were not serious although the flow concentrated near the tunnel center line. The tunnel size was adequate for all discharges and was filled approximately 20 percent at the downstream portal for the maximum design discharge of 11,900 cfs.

Flow in stilling basin. The water was distributed to a nearly uniform depth in the stilling basin chute for discharges to approximately 3,000 cfs. Between 3,000 cfs and 11,900 cfs, the concentration of water about the chute center line increased with discharge. The two, 18.75-foot-high dividing walls in the chute stabilized the flow for all discharges. Effective energy dissipation occurred with the 2.5-foot-high by 2.5-foot-wide chute blocks (Figure 13A) and the seven 8-foot-high streamlined baffle blocks (Figure 18C). The 8-foot-high dentated sill at the basin exit deflected the flow upward to prevent erosion of the exit channel floor. Turbulence and wave action increased with discharge but flow conditions in the stilling basin were good. The riprap protection of the exit channel was in general adequate for the waves generated by the basin.

Tail-water elevation required for basin operation. The maximum solid water surface in the stilling basin for a discharge of 11,900 cfs and a tail-water elevation of 3466.5 indicated a training wall freeboard of 7.5 feet (Figure 24A). Waves carried water over the walls, but no serious damage should occur to the backfill protected by riprap (Figure 4). When the tail water was lowered to elevation 3461.5, 5 feet below the normal elevation of 3466.5 for a discharge of 11,900 cfs, the upstream end of the jump moved downstream and the chute blocks were visible. The upstream end of the jump moved to the baffle blocks when the tail water was decreased to elevation 3456, 10 feet below the computed normal tail water. Tail-water elevation below 3456 allowed the water to deflect up and over the baffle blocks through the downstream end of the stilling basin and into the exit channel. Severe erosion damage to the exit channel would result from operation of the basin at the maximum discharge with a tail water below elevation 3456.

Release of water through the outlet works for routing flood waters may be necessary with the exit channel and river at low stage. To prevent a sweepout of the basin at any discharge when the gates are first opened, the gate opening time should be controlled to allow the tail-water elevation to adjust to the minimum elevation shown on Figure 24B. Control of the discharge in this manner would prevent any damage to the stilling basin and exit channel by the jump being swept from the basin.

Operation of gates. Flow conditions at the maximum design head were observed for unequal openings of the gates. Interference of the unbalanced quantities of water from the gates caused ridges to form in unsymmetrical patterns in the tunnel. The ridges within the tunnel were not objectionable but the water concentrated along one training wall or the other, depending on the flow unbalance, to cause a rotational flow within the stilling basin and reduce its effectiveness. However, waves generated in the basin by the unbalanced flow did not seriously overtop the training walls. Although no material was deposited in the model basin, some bed material from the exit channel might be moved into the basin to cause an abrasive damage to the floor and walls. Better flow conditions resulted from a symmetrical operation of the gates, but no critical action should result from operation at unequal openings.

Coefficient of discharge for outlet gates and flow passages. A coefficient of discharge curve for the recommended outlet gate structure is shown in Figure 6B. The capacity of the outlet works was approximately 11,900 cfs for both gates fully opened and operating at a total head of 308 feet at the entrance to the gate section.

Emergency closure of outlet works. The 9- by 20-foot diversion gates will be used only for emergency closure of the outlet works after installation of the 6- by 7.5-foot regulating slide gates. Flow conditions were observed as a diversion gate was operated to represent emergency closure with the discharge from the gate passing through a fully opened regulating gate. With no air admitted to the chamber between the diversion gate and the entrance to the regulating gate structure (Figures 3 and 7A) the pressure in the chamber was above atmospheric for diversion gate openings from 20 down to approximately 6 feet. At the 6-foot opening the area under the large gate was approximately equal to the area of the wide open regulating gate and the jet produced an ejector action. This action resulted in a partial evacuation of the water from the chamber and a reduction in the pressure above the jet. As the gate opening was decreased to approximately 0.5 foot, the pressure in the model chamber was reduced gradually to a subatmospheric pressure that scaled to vapor pressure for the prototype. At this opening the vacuum was relieved abruptly by air from downstream and a surging of the water took place in the chamber between the gates. Further closure of the emergency gate resulted in a shooting flow through the passage of the regulating gate structure.

Air admission to the chamber between the gates resulted in a better transition from a control of the discharge by the regulating gate water passage to a control by the diversion gate. Pressures were still above atmospheric for openings of the emergency gate between 20 and 6 feet. Between gate openings of 6 feet and 1.5 feet, the flow in the chamber was turbulent; but the water was discharged through the regulating gate structure without severe subatmospheric pressures. Below the 1.5-foot opening, the water passed directly from the gate through the regulating gate structure with a minimum of turbulence.

An air vent into the chamber would have to extend to the maximum reservoir water surface or be interconnected with the vents for the downstream gates and controlled by a check valve (Figure 3). The need for such an arrangement was questionable, particularly since the possibility of emergency closure with the downstream gate wide open was remote and the period of such operation so short. Prolonged operation of the diversion gates, between openings of 6 feet and fully closed with or without air admission is not recommended because of possible damage to the diversion gate by cavitation and the surging of flow in the chamber between the gate sections.

Outlet Works Used as Diversion Structure

Description of model. After final details for the outlet works had been determined, a check was made to see if the pertinent parts of the structure would be satisfactory for diverting flood waters during construction. The regulating gates were removed from the model, and the diversion passages, the equivalent of 9 feet wide and 21 feet high, were placed downstream of each of the large diversion gates (Figure 5C). The 25-foot horseshoe-shaped tunnel and the stilling basin were retained as recommended for the outlet works. Observations of the flow conditions for symmetrical gate operation were made for discharges ranging to the maximum design quantity of 28,300 cfs. The tests included discharges of 4,700, 11,900, and 20,000 cfs (Figures 25, 26, 27, and 28).

Flow in diversion gate flow passages. Water from the diversion gates flowed through the 9- by 21-foot flow passages without excessive turbulence. Fins of water were deflected upward on the side walls of the passages just downstream of the gate slots. These fins were small and did not interfere with the flow of water through the passages or the aeration of the flow by the air ducts located in the top of the downstream gate frame. The passages were partially filled at gate openings smaller than approximately 90 percent. A transition to full conduit conditions occurred at this opening without severe surging or pressure changes. Flow conditions in the diversion gate flow passages were satisfactory for all discharges.

Flow in transition and tunnel. The ridges of water in the tunnel below the diversion gate structure were generally smaller than those with the regulating gate structure. The change was attributed to the lower water velocity and the fact that the inner walls of the diversion flow passages were continuous with the sides of the center wall in the transition downstream of the diversion flow passages (in contrast to the 1.5-foot offset at the exit of the regulating gate structure of the outlet works). Water flowed from the diversion flow passages and was guided by the center wall to the tunnel with less interference of the jets at the downstream end. A crowding of the water toward the center of the tunnel along the outside walls of the transition and tunnel was evident (Figures 25A, 26A, and 27A). A ridge of water downstream of the end of the center wall in the transition had sufficient height to flow against the top of the tunnel for discharges between 25,000 and 28,300 cfs (Figure 28A) but did not totally obstruct the tunnel. The tunnel size was adequate for all discharges and was approximately 65 percent full at the outlet portal near the stilling basin chute entrance for a discharge of 28,300 cfs.

Discharging water from a single gate caused an asymmetrical flow distribution in the tunnel. The single jet expanded from the end of the center wall in the transition to rise up the opposite side of the tunnel and form a ridge of water which reflected from side to side through the remainder of the tunnel. At maximum gate opening, the flow reached the top of the tunnel but did not prevent air passage in the tunnel (Figure 29A). An unbalanced distribution of the water in the chute and stilling basin induced a flow eddy in the basin. The eddy did not extend beyond the end of the basin and did not cause material to be deposited on the basin floor. The energy for a discharge of 15,750 cfs was effectively dissipated by the basin (Figures 29B and C).

Flow in stilling basin and exit channel. Effective energy dissipation occurred in the stilling basin for discharges to approximately 20,000 cfs (Figures 25, 26, and 27). Turbulence and wave action in the basin increased with discharge, but only a small percentage of the waves overtopped the training walls at this discharge (Figures 30A and B). The stilling basin dividing walls stabilized the chute flow for all discharges.

Between discharges of 20,000 and 25,000 cfs the flow in the stilling basin was unstable and the jump neared the sweep-out condition at normal tail water for discharges greater than 25,000 cfs (Figures 28B and C). Severe overtopping of the walls from the wave action (Figure 30C) would probably cause damage to the riprap protected backfill at the training walls. Erosion damage to the side slopes of the exit channel would occur at the cut-off walls and extend downstream. There was no evidence of an undermining of the basin floor but rather a deposit on the channel bottom of the material eroded from the side slopes. A minimum of damage to the exit channel of the stilling basin will occur if the discharge is limited to approximately 20,000 cfs.

Pressures on leaf of 9- by 20-foot diversion gates. The model gates were constructed from preliminary details of the gate design shown in Figure 31. Pressures were measured on the leaf, at the slot, and on the downstream frame of the model gate. The pressure measurements at the gate bottom disclosed this part of the prototype gate would be subjected to a subatmospheric pressure equal to the vapor pressure of water when the gate opening was small. The subatmospheric pressure occurred on the bottom of the gate leaf for gate openings between 0 and 0.8 foot (Figure 32A). A contraction and expansion of the flow (short tube flow) between the floor of the gate and the bottom plate of the gate leaf caused the subatmospheric pressure. Perforation of the bottom plate with twelve 2-inch holes placed on 8-1/2-inch centers 12 inches downstream of the gate lip across the width of the leaf to relieve the subatmospheric pressures by admission of air was incorporated in the final gate design. At partial gate opening air in the tunnel can pass through these holes to vent the jet under the gate. A subatmospheric pressure of approximately 9 feet of water occurred on the gate bottom for the maximum opening of 20 feet with the gate and exit conduit flowing full (Piezometer 16, Figure 32A). The pressure was not reduced sufficiently to cause cavitation for the wide open gate position and operation should be satisfactory.

Pressures at gate slot deflector. A deflector at the upstream edge of the gate slot was designed to deflect the flow past the gate slot and to prevent a subatmospheric pressure at the downstream corner of the slot. A 13-1/4-inch-long wedge that extended 3 inches out from the frame wall formed the deflector. An offset, 2-1/8 inches long by 1-1/2 inches wide, at the downstream end of the deflector facilitated the installation of a rubber seal in the prototype gate. Piezometers were located in the offset of the deflector at 1.25 and 10 feet above the gate floor (Figure 32B).

As the gate leaf was raised near Piezometer 1 the pressure changed from atmospheric at a 1.6-foot opening to vapor pressure at a 1.8-foot opening and back to atmospheric at a 2.2-foot opening. The pressure changed at Piezometer 7 from atmospheric at a gate opening of 10.2 feet to vapor pressure at 10.4 feet and back to atmospheric at 11.8 feet (Figure 32B).

The flow condition that caused the subatmospheric pressure was apparently the combined flow contractions of the gate leaf and the deflector. A separation of the water from the surface of the deflector at the upstream end of the offset was prevented by the flow down the gate leaf. The water at the junction of the leaf and deflector flowed out toward the gate slot in a downward direction to close the offset and cause a subatmospheric pressure. The subatmospheric pressure that occurred within the offset moved with the gate and could thus be expected at approximately all gate openings. The possible exceptions being those gate positions near full opening where the flow down the leaf was very small. With these pressure conditions cavitation and vibration would be expected to occur on the prototype.

The slope of the deflector was extended to the downstream end to eliminate the offset and, it was hoped, the cause of the lower pressures. This deflector, 13-1/4 inches long and 3 inches wide at the downstream end, provided a definite spring point that would cause the water to flow across the slot (Figure 32B). Piezometers 1, 7, and 24 were located in the downstream face of the deflector at 1.25, 10, and 5 feet above the floor. This modification resulted in pressures at the deflector that were slightly subatmospheric but satisfactory (Recommended Deflector, Figure 32B). The pressure at Piezometer 24 seemed unreasonably low so the reason was investigated. After an examination of the surface and a study of the effect of surface irregularities on the pressure, it was decided that the lower subatmospheric pressure at Piezometer 24 was caused by a surface irregularity on the model at the piezometer and not to a flow condition. A deflector, 13-1/4 inches long by 3 inches wide at the upstream end of the slot and without an offset produced satisfactory flow conditions (Section V-V, Figure 31).

Pressures in gate slot. Piezometer 25 immediately downstream of the deflector on the floor within the gate slot measured a subatmospheric pressure of 12 feet of water for a gate opening of approximately 3.6 feet (Figure 32C). The subatmospheric pressure was apparently caused by an eddy that was formed over the piezometer by the deflection of water from the gate leaf into the slot. Pressures on the upstream side of the slot at Piezometer 20 (1.875 feet above the gate floor and 5.6 inches within the slot) indicated a slight subatmospheric pressure but the pressure at Piezometer 22 (10.625 feet above the floor) was above atmospheric for all gate openings (Figure 32D). The pressures at the outside of the slot at Piezometers 2, 8, and 11 were above atmospheric to a gate opening of approximately 19 feet. The pressures at 2 and 8 remained above atmospheric, but the pressure at Piezometer 11 near the top of the gate slot was reduced to 6 feet below atmospheric at the 20-foot opening as the conduit flowed full (Figure 32D). The slot pressures were satisfactory because none of the subatmospheric pressures indicated a cavitation pressure.

Pressures on downstream gate frame. The gate frame was tapered from 9 feet 3 inches wide at the downstream edge of the gate slot to 9 feet wide in a distance of 3 feet 10-1/4 inches downstream of the slot. This taper, in conjunction with the gate slot deflector, resulted in a flow of water across the slot to the downstream frame. Pressures measured by Piezometers 3, 4, 9, and 12 on the side of the downstream frame at the end of the gate slot and Piezometer 5 on the gate floor evidenced no appreciable flow into the slot. A slight subatmospheric pressure occurred as the top of the jet from the gate flowed past the piezometer (Figure 33A). The 3-inch-wide deflector and the 1-1/2-inch offset in the downstream frame with the converging taper to the gate width in 3 feet 10-1/2 inches of length were satisfactory for protection of the gate slot from the effects of cavitation.

The angle at the end of the tapered gate frame and the beginning of the conduit was small and no subatmospheric pressures occurred downstream of the junction. Piezometers 6, 10, and 13, located downstream of the junction, measured pressures above atmospheric for all gate openings (Figure 32A). The joint of the gate frame and the conduit should be smooth to prevent cavitation pressures.

Capacity of 9- by 20-foot gates and flow passages. A calibration of the diversion gates and water passages disclosed sufficient capacity to discharge approximately 31,000 cfs for a design total head of 201 feet at the gate. The maximum coefficient of discharge for the gates and passages was approximately 0.77 (Figure 33).

Interior - Reclamation - Denver, Colo.

FIGURE 1
Report Hyd 397

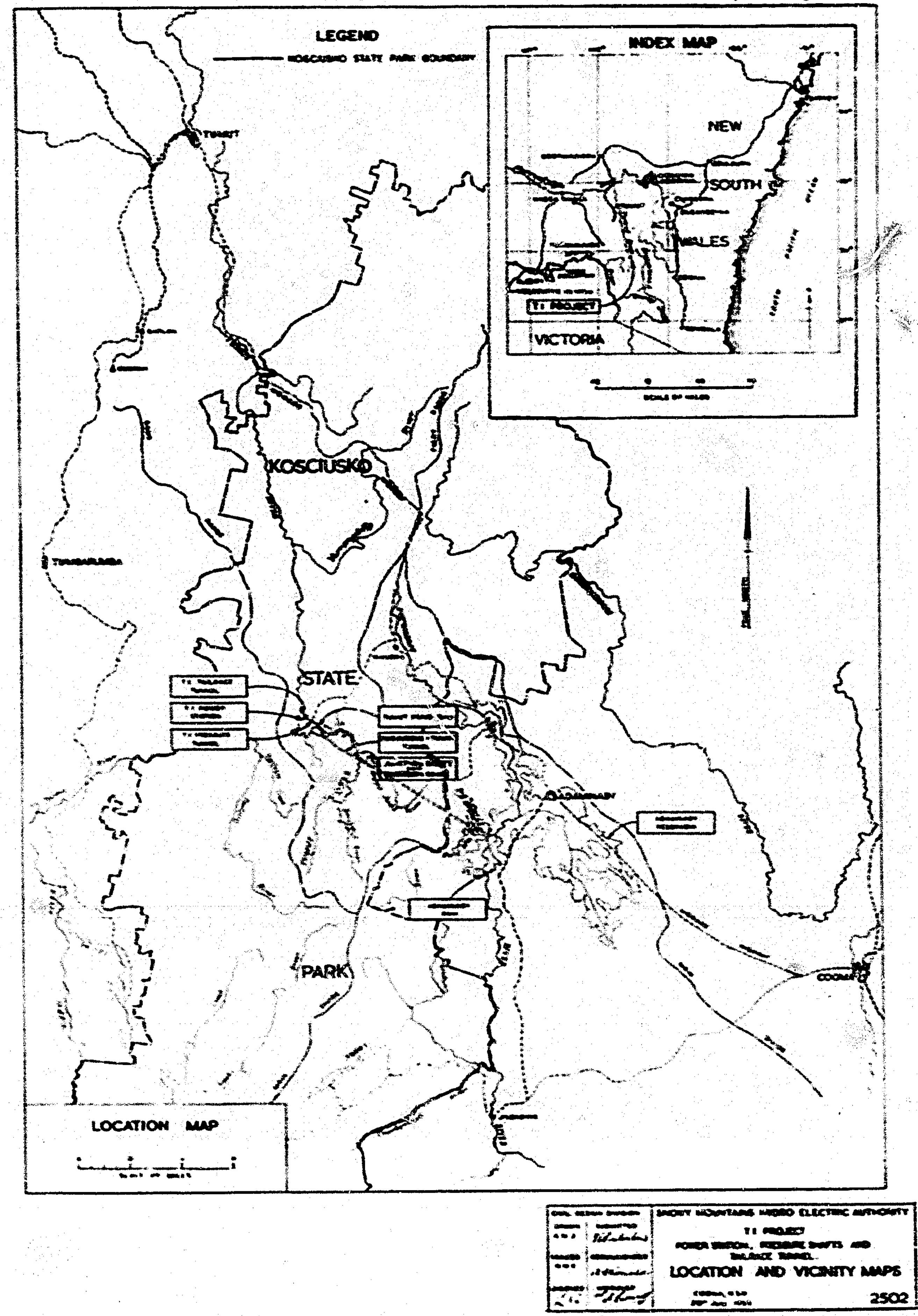
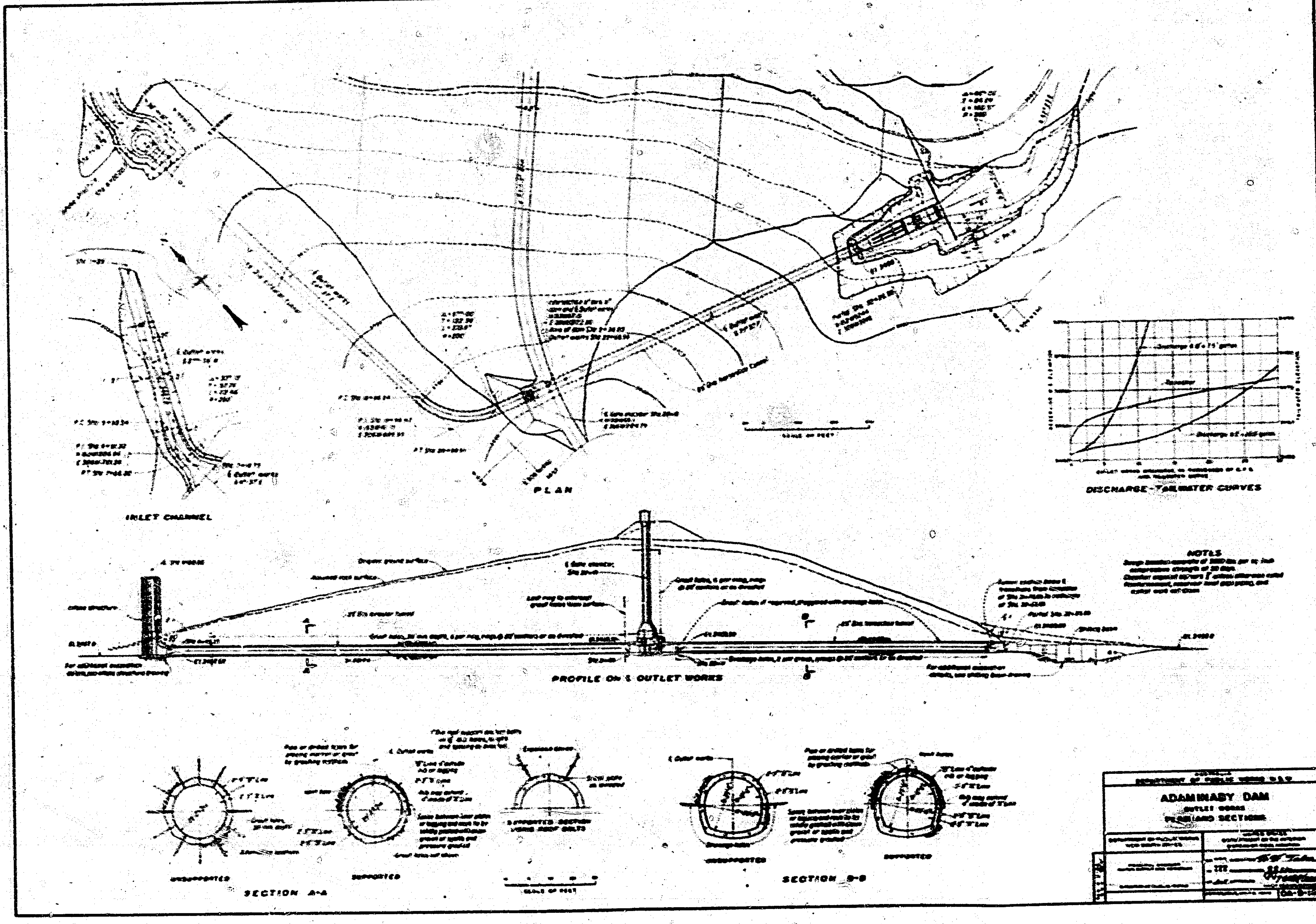


FIGURE 2
REPORT HYD. 397



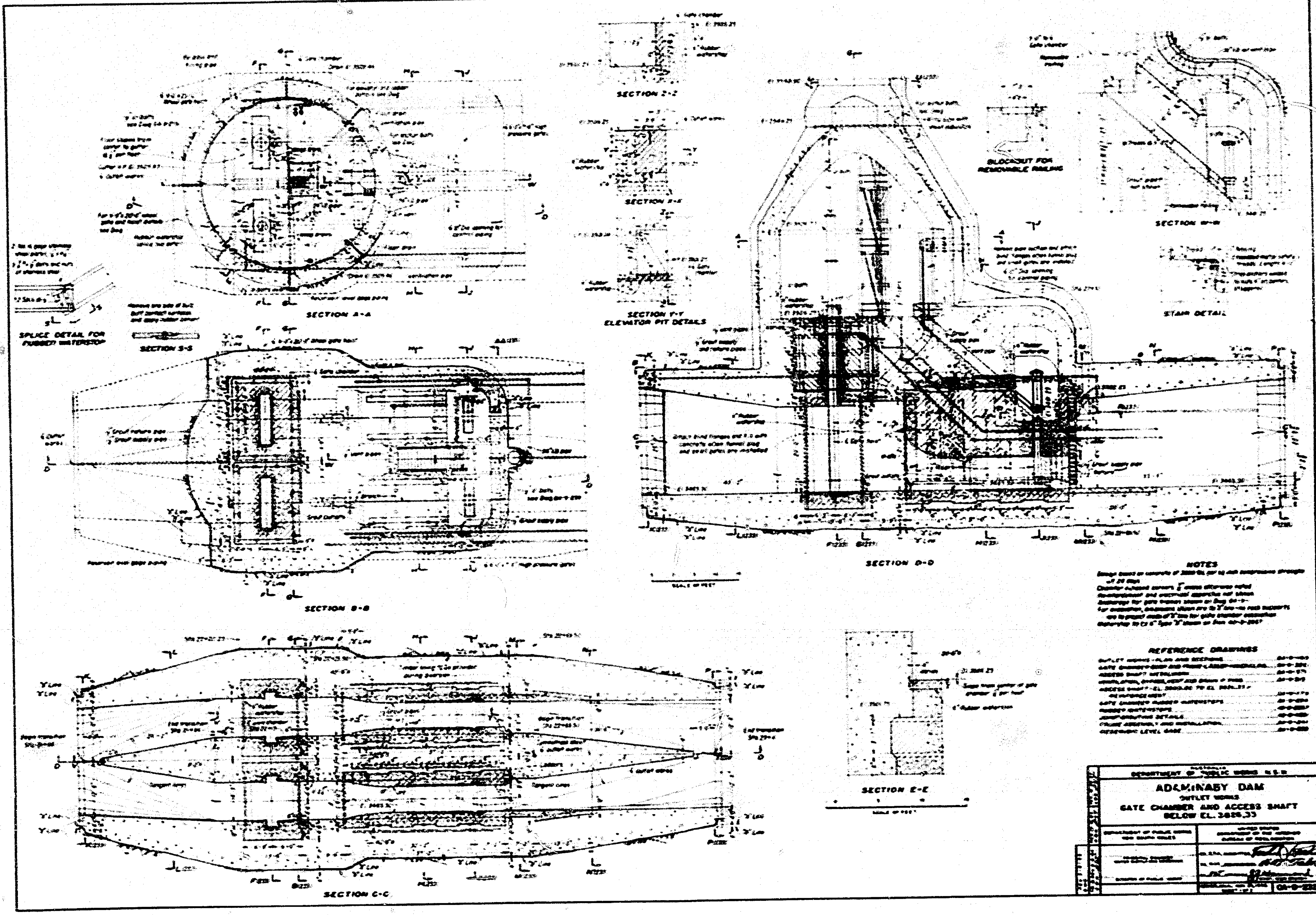
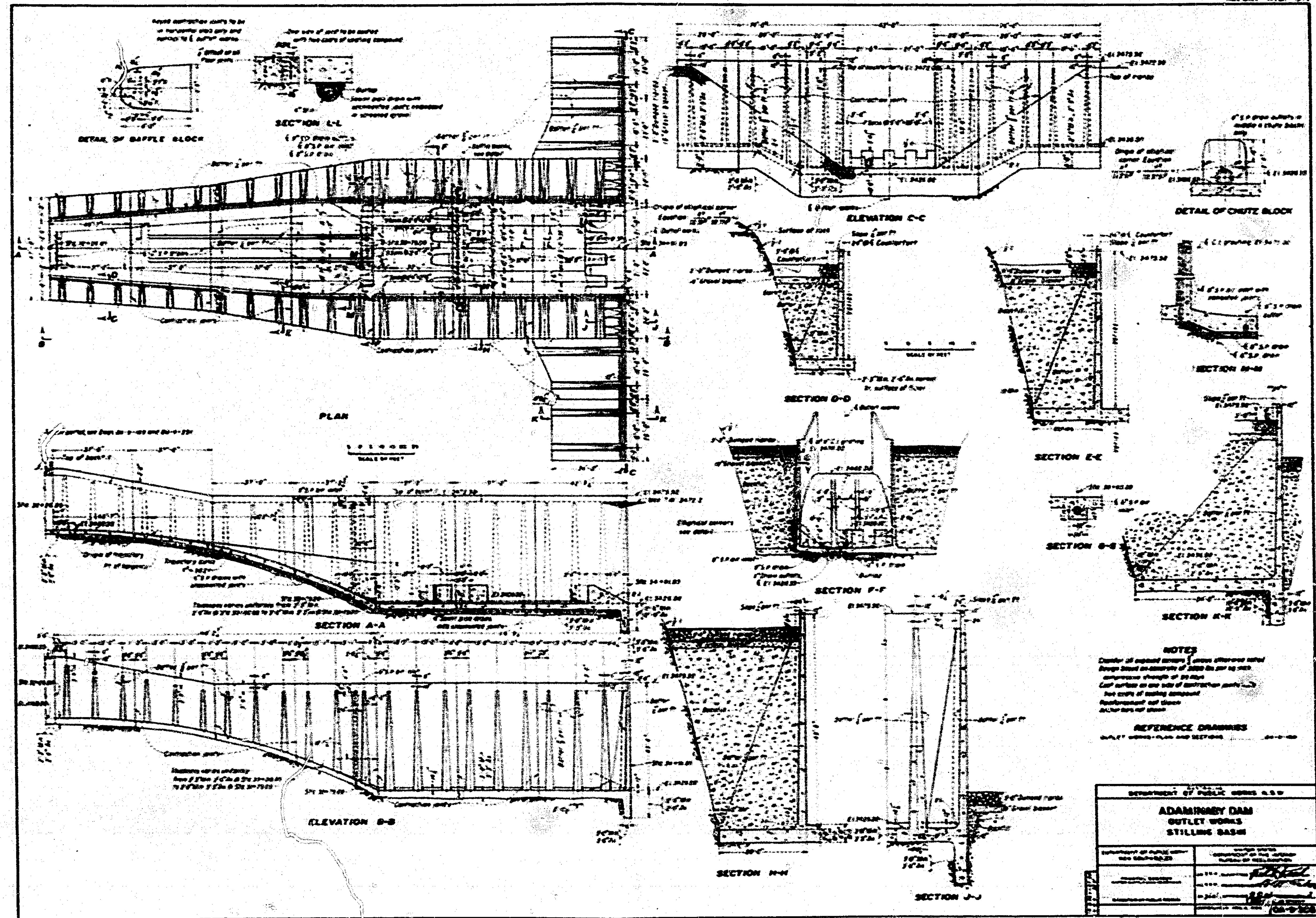
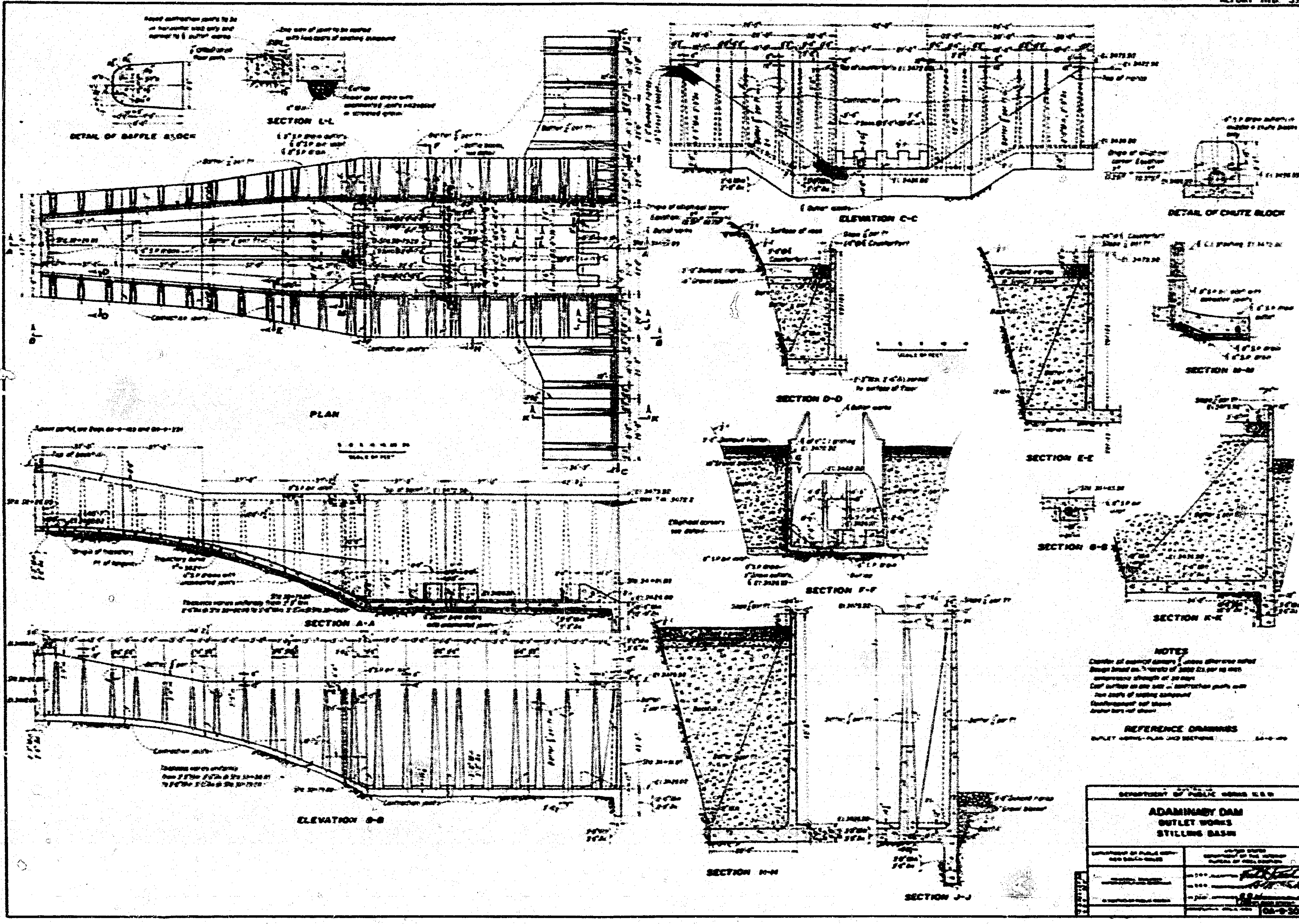
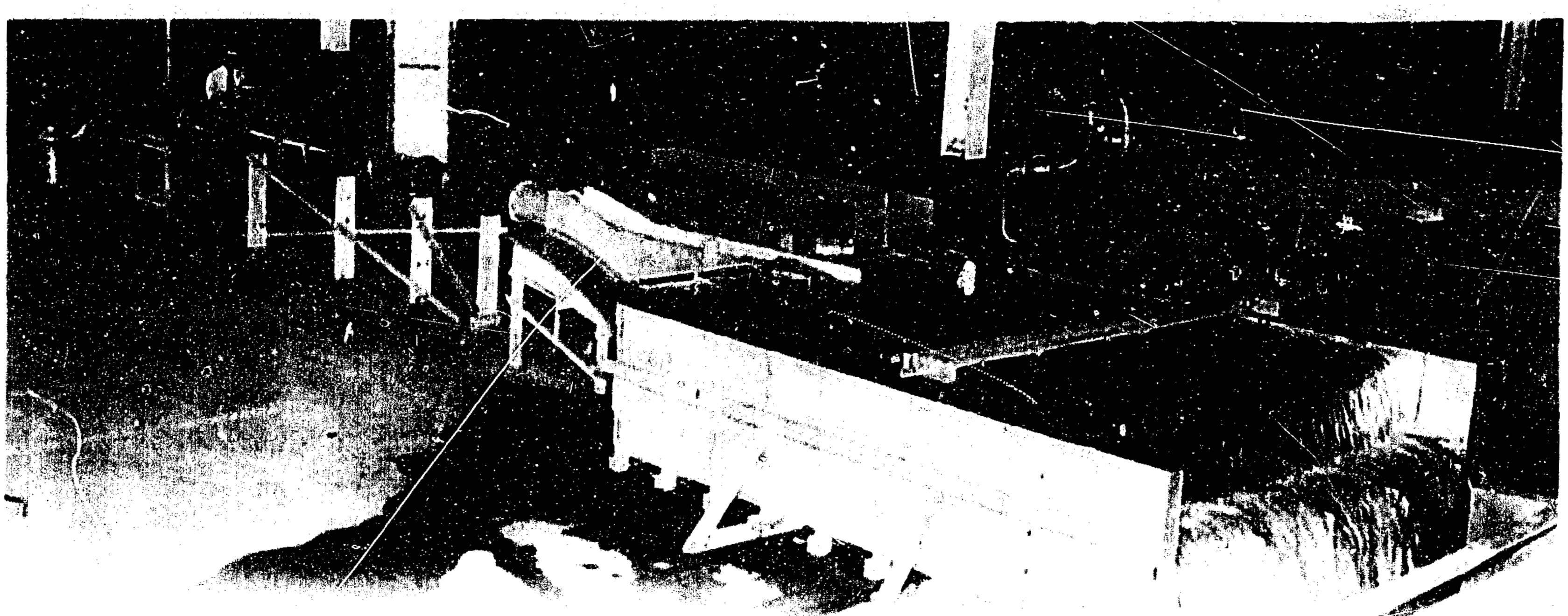

SECTION A-A
SPLICE DETAIL FOR RUBBER WATERSTOP
SECTION S-S
SECTION Z-Z
SECTION X-X
SECTION Y-Y
ELEVATOR PIT DETAILS
BLOCKOUT FOR REMOVABLE RAILING
SECTION W-W
STAIR DETAIL
SECTION B-B
SECTION D-D
NOTES
REFERENCE DRAWINGS
SECTION C-C
SECTION E-E
ADAMINABY DAM
OUTLET WORKS
GATE CHAMBER AND ACCESS SHAFT
BELOW EL. 3626.33

FIGURE 4
REPORT HYD. 397




DETAIL OF BAFFLE BLOCK
SECTION L-L
PLAN
SECTION A-A
ELEVATION B-B
ELEVATION C-C
DETAIL OF CHUTE BLOCK
SECTION D-D
SECTION E-E
SECTION M-M
SECTION F-F
SECTION G-G
SECTION K-K
SECTION N-N
SECTION J-J
NOTES
REFERENCE DRAWINGS
DEPARTMENT OF PUBLIC WORKS N.S.W.
ADAMINABY DAM
OUTLET WORKS
STILLING BASIN

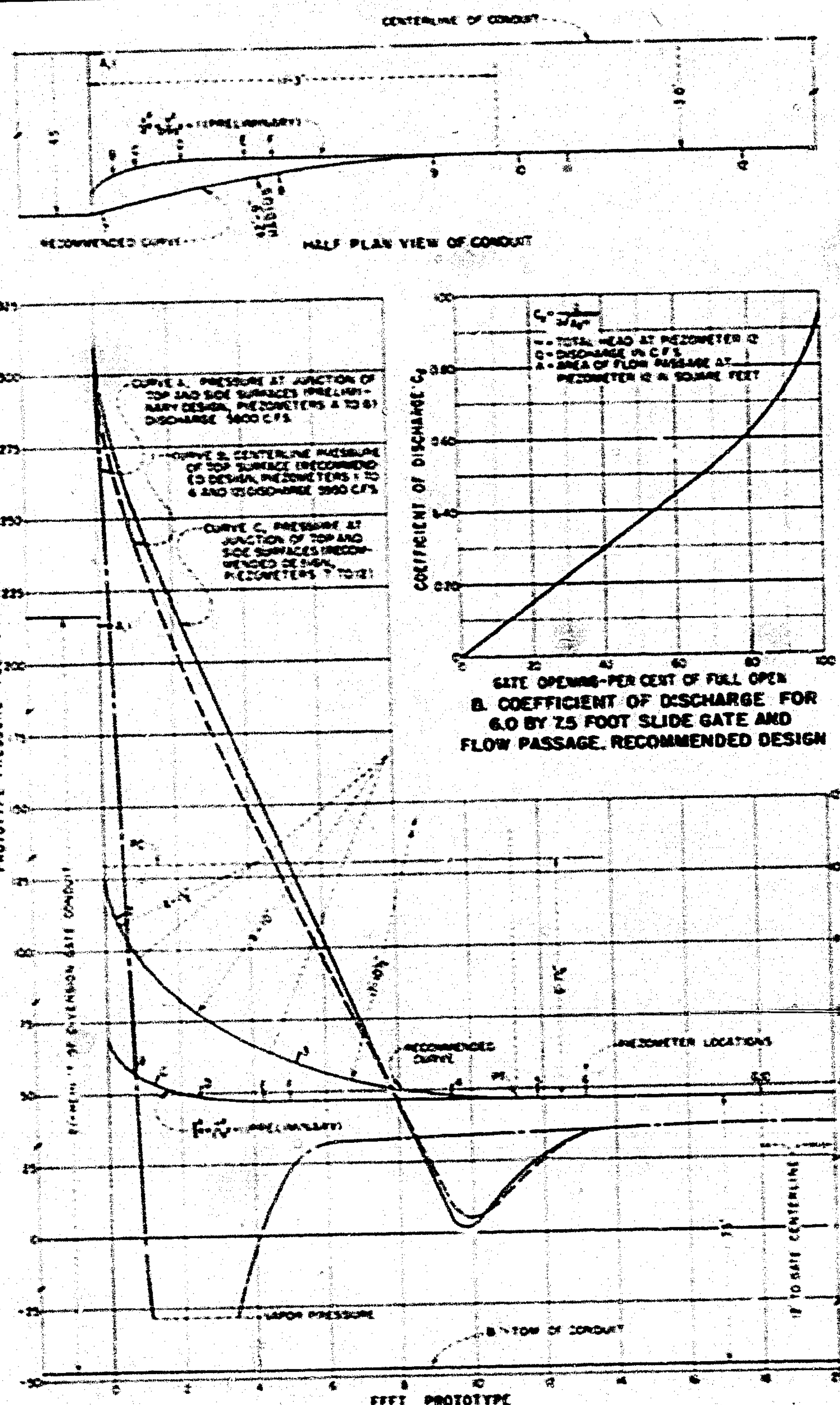


A. Discharge Representing 11,900 cfs through Diversion Gates and Flow Passages

B. Outlet Works Gate Structures and Tunnel Transition

C. Diversion Gates, Flow Passages and Tunnel Transition

ADAMINABY OUTLET WORKS
1:30 SCALE MODEL



B. COEFFICIENT OF DISCHARGE FOR 6.0 BY 7.5 FOOT SLIDE GATE AND FLOW PASSAGE, RECOMMENDED DESIGN

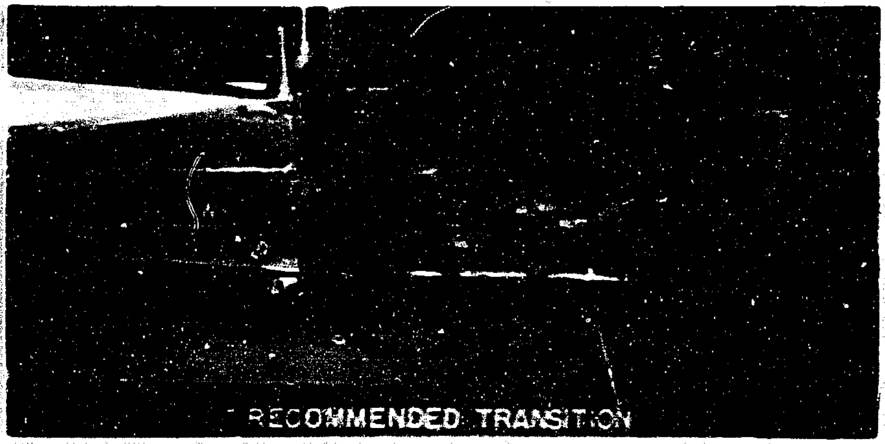
ELEVATION VIEW OF CONDUIT

A. PRESSURES FOR PRELIMINARY AND RECOMMENDED ENTRANCE TRANSITION TO 6.0 BY 7.5 FOOT OUTLET REGULATING GATE FLOW PASSAGE

ADAMINABY OUTLET WORKS

PRESSURES AND COEFFICIENT OF DISCHARGE FOR 6.0 BY 7.5 FOOT OUTLET GATES AND FLOW PASSAGES

ALL DATA FROM 1 TO 30 SCALE MODEL

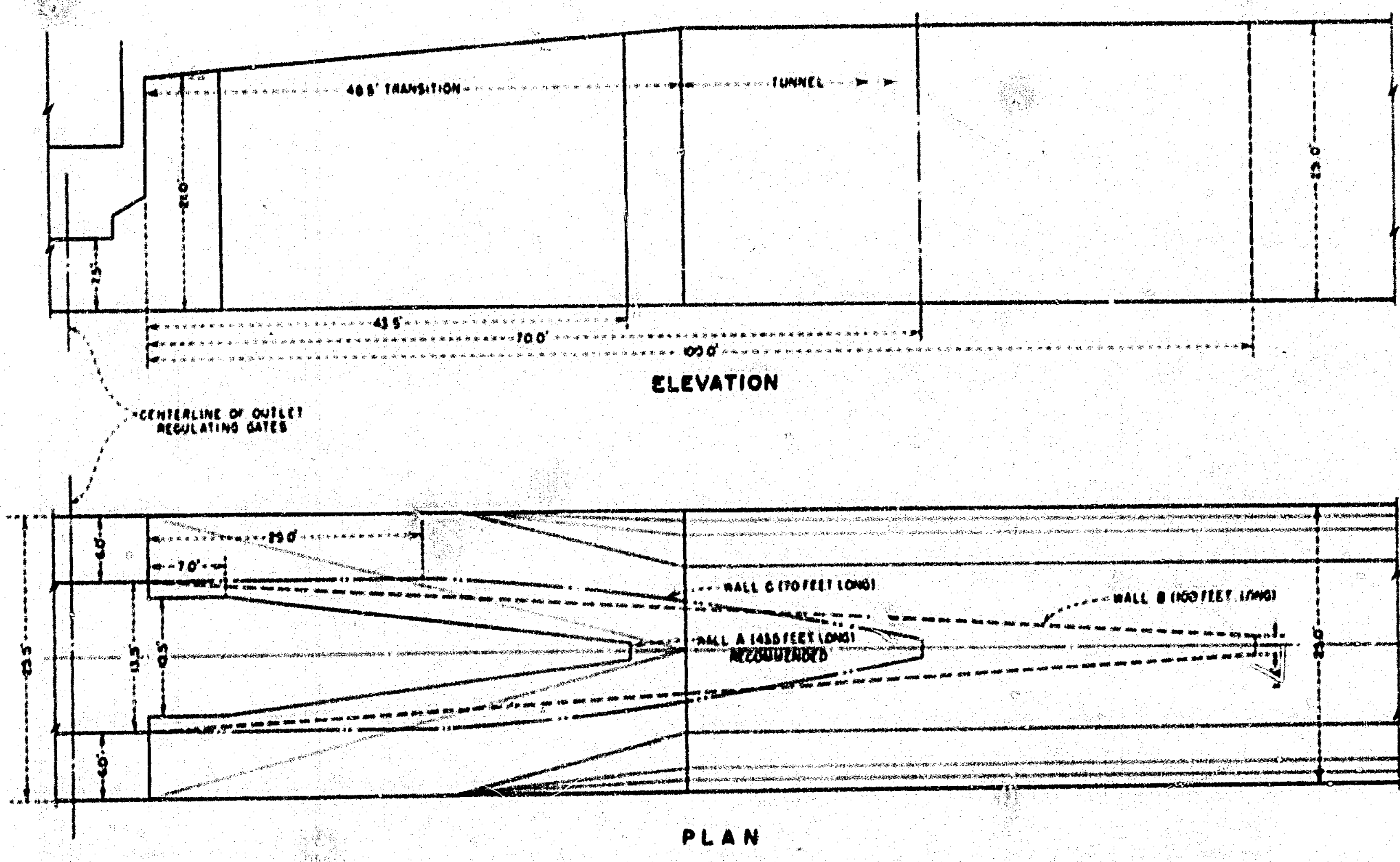


A. Emergency Gates, Preliminary and Recommended Entrance Transitions to Outlet Flow Passages, Outlet Gates, and Tunnel Transition

B. Discharge 5950 cfs from Right-hand Regulating Gate - Note Ridge of Water Reflected Across Tunnel - Flow Left to Right

C. Stilling Basin Operation for One Outlet Gate Open Discharge 5950 cfs, Tail-water Elevation 3464

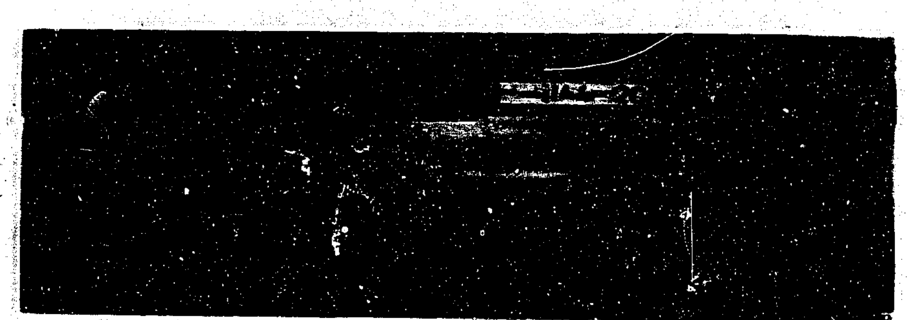
ADAMINABY OUTLET WORKS
FLOW CONDITIONS IN TUNNEL AND STILLING BASIN
WITH ONE REGULATING GATE OPEN



ADAMINABY OUTLET WORKS

TUNNEL TRANSITION AND DIVIDING WALL BELOW GATE STRUCTURE

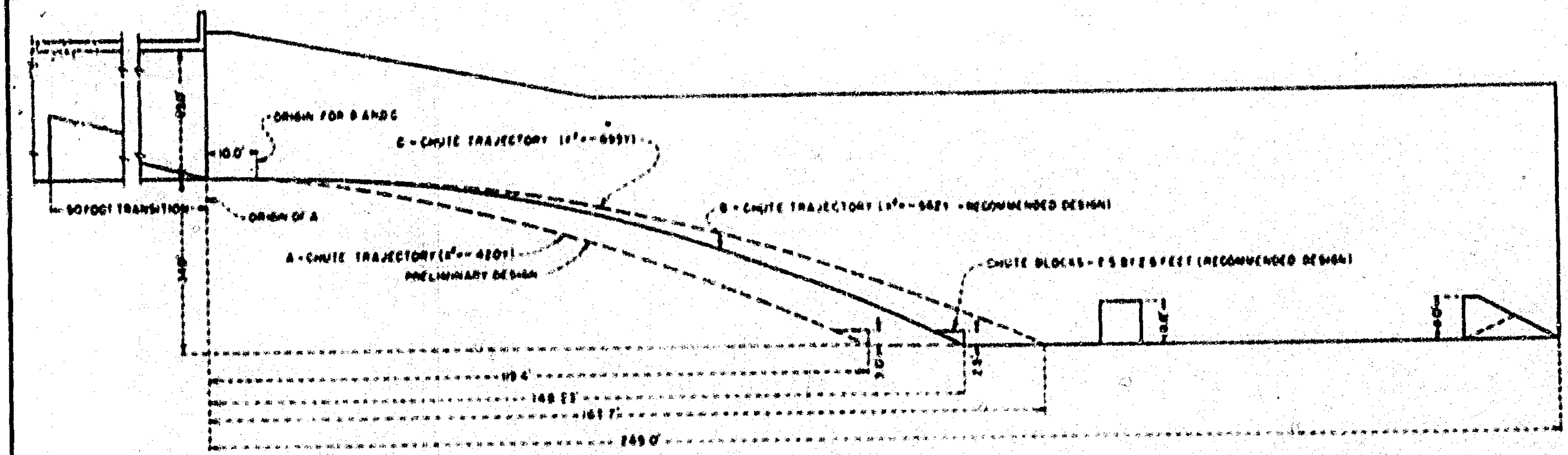
A. Recommended Dividing Wall 43.5 Feet Long and 10.5 Feet Thick



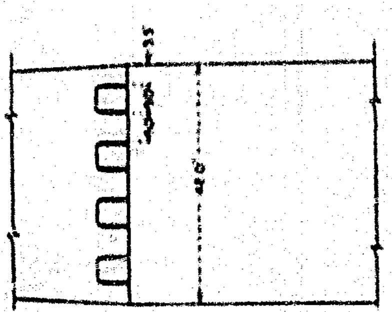
B. Dividing Wall 100 Feet Long and 13.5 Feet Thick

C. Div[illegible]all 70 Feet Long and 13.5 Feet Thick

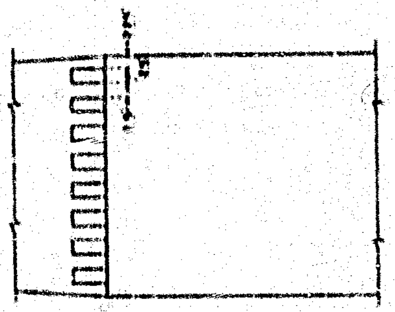
ADAMINABY OUTLET WORKS
FLOW CONDITIONS IN AND BELOW TUNNEL TRANSITION
WITH MAXIMUM DISCHARGE 11,990 CFS
CONTROLLED BY REGULATING GATES



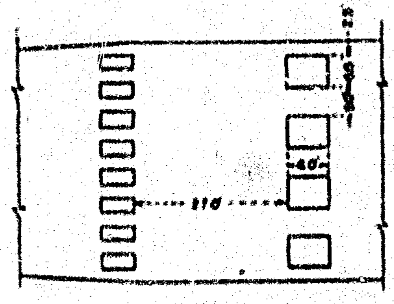
A. STILLING BASIN CHUTE FLOOR PROFILE TRAJECTORIES



B. CHUTE BLOCKS
3.0 FEET HIGH BY 5.0 FEET WIDE
PRELIMINARY DESIGN



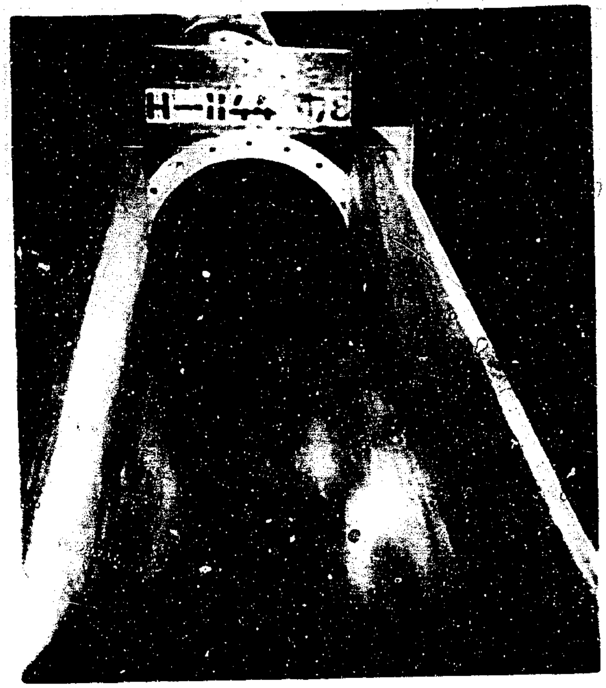
C. CHUTE BLOCKS
2.5 BY 2.5 FEET-PRELIMINARY ARRANGEMENT
OF RECOMMENDED CHUTE BLOCKS



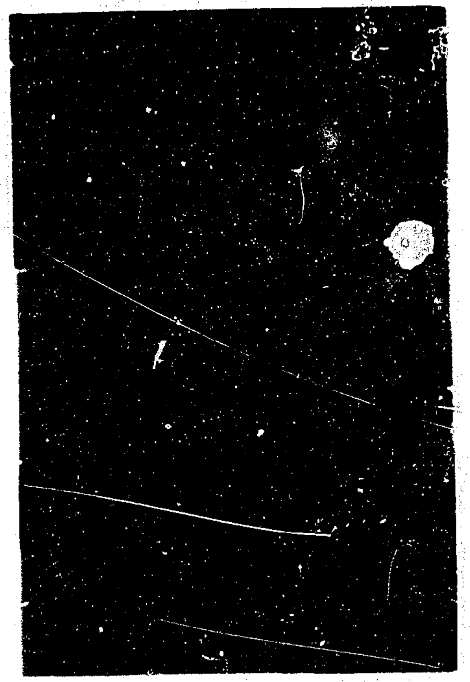
D. BAFFLE BLOCKS
6.0 FEET HIGH BY 5.5 FEET WIDE
PRELIMINARY DESIGN

ADAMINABY OUTLET WORKS

DETAILS OF CHUTE FLOOR PROFILE — CHUTE BLOCKS AND BAFFLE BLOCKS

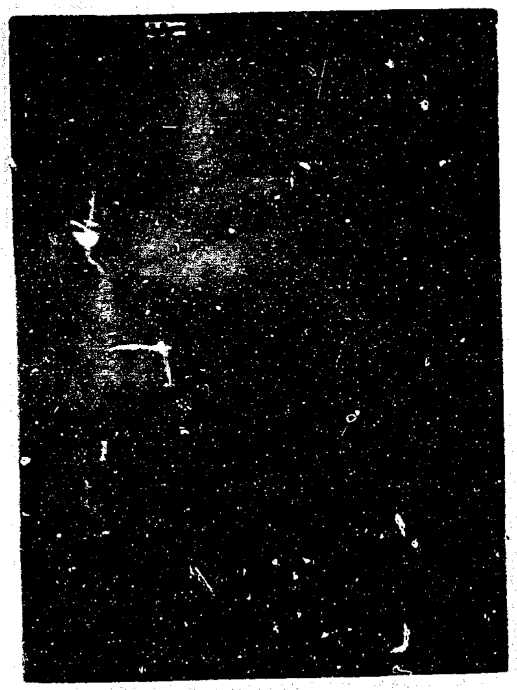


A. Flow Concentration at Center of Tunnel Outlet Portal



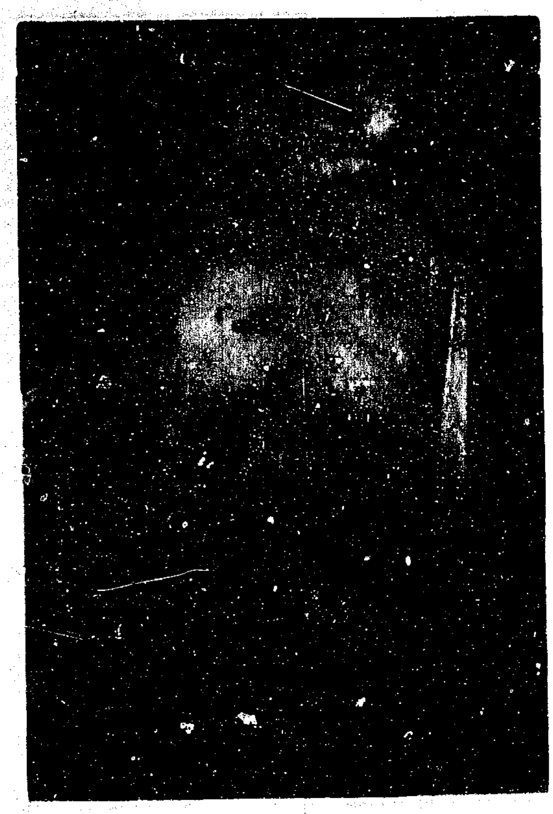
B. Turbulent Action in Stilling Basin

Chute Floor Profile Trajectory $X^2 = 562Y$



C. Turbulent Action in Stilling Basin
Chute Floor Profile Trajectory
$X^2 = 695Y$

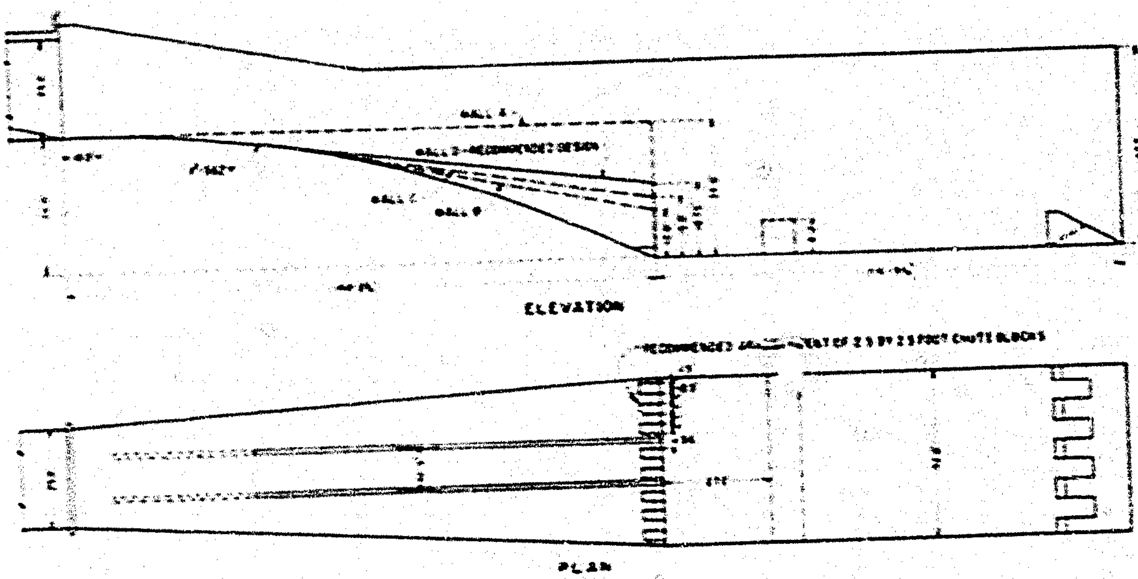
ADAMINABY OUTLET WORKS
WATER DISTRIBUTION IN CHUTE AND STILLING BASIN
FOR DIFFERENT CHUTE FLOOR PROFILES
DISCHARGE 11,900 CFS - TAIL-WATER ELEVATION 3466.5



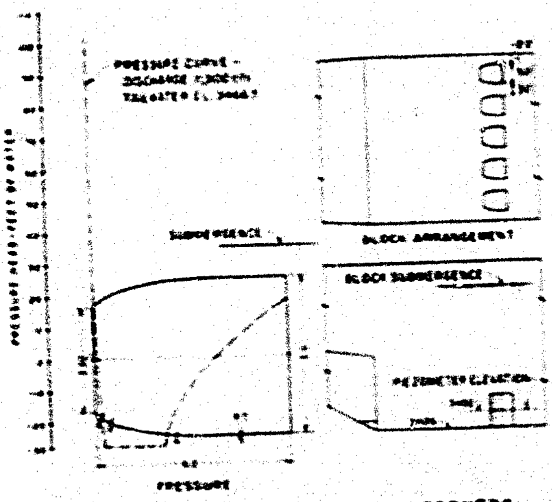
A. Increased Effectiveness of the Basin for Energy Dissipation by Use of Baffle Blocks in Stilling Basin

B. Waves and Turbulence Resulting from Unstable Direction of Jet Flow Note Wave at Left Training Wall and Eddy at Right

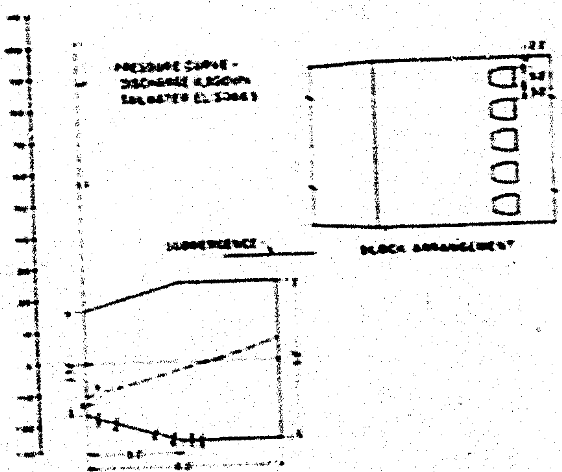
ADAMINABY OUTLET WORKS
EFFECT OF THE PRELIMINARY BAFFLE BLOCKS ON STILLING BASIN



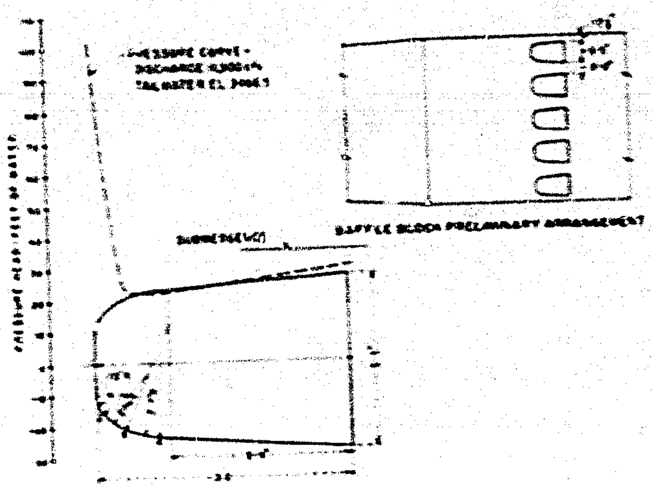
A. CHUTE DIVIDING WALLS



B. BAFFLE BLOCK WITH UPSTREAM CORNERS STREAMLINED TO A JET PROFILE



C. BAFFLE BLOCK WITH BEVELED UPSTREAM CORNERS



D. BAFFLE BLOCK D-3RADII-RECOMMENDED DESIGN

ADAMINABY OUTLET WORKS

DETAILS OF CHUTE DIVIDING WALLS AND BAFFLE BLOCKS

A. Chute Dividing Walls - 18.75 Feet High - 102 Feet Long-- Recommended Design

B. Chute and Stilling Basin Flow With 4 Preliminary Baffle Blocks Discharge 11,900 cfs

C. Wave Action at Stilling Basin Exit-- Tail-water Elevation 3466.5 Discharge 11,900 cfs

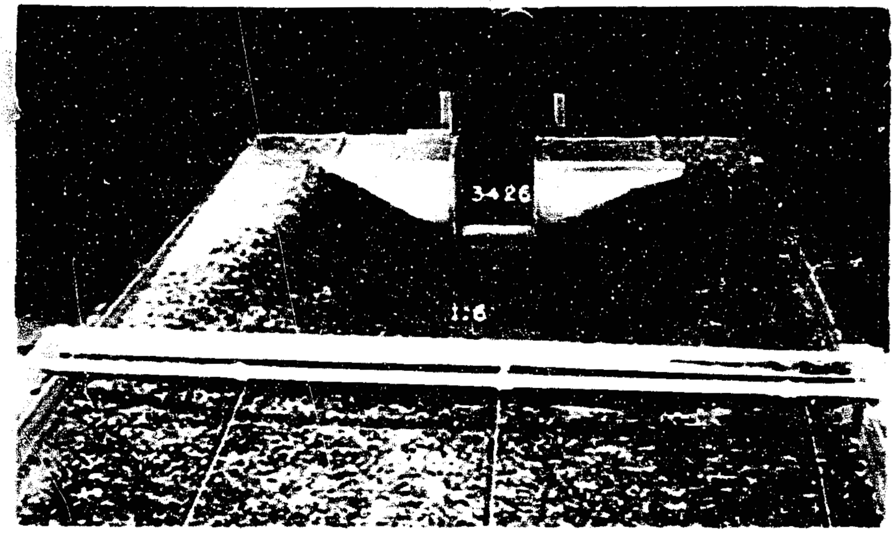
ADAMINABY OUTLET WORKS
BASIN OPERATION WITH 18.75 FOOT HIGH DIVIDING WALLS - RECOMMENDED CHUTE BLOCKS AND PRELIMINARY BAFFLE BLOCKS

A. Chute Dividing Walls - 18.75 Feet High - 102 Feet Long-- Recommended Design

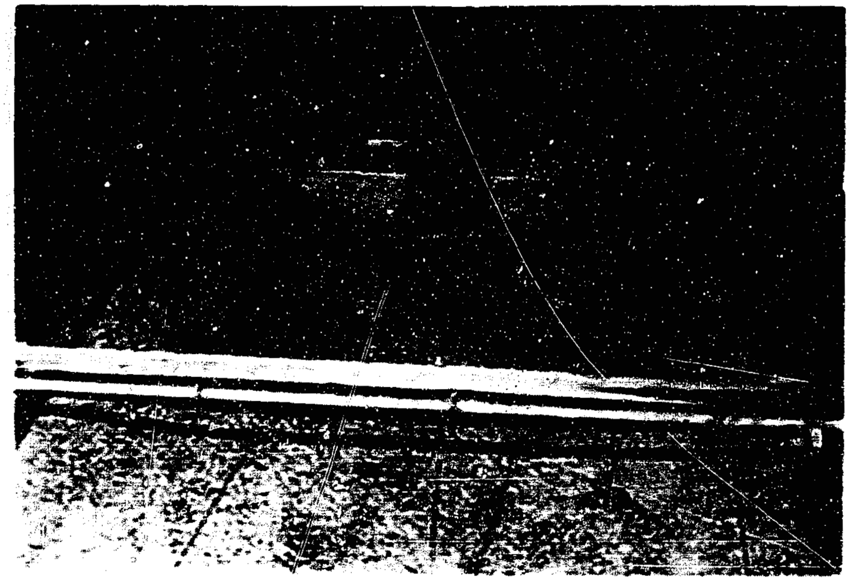
B. Chute and Stilling Basin Flow With 4 Preliminary Baffle Blocks Discharge 11,900 cfs

C. Wave Action at Stilling Basin Exit-- Tail-water Elevation 3466.5 Discharge 11,900 cfs

ADAMINABY OUTLET WORKS
BASIN OPERATION WITH 18.75 FOOT HIGH DIVIDING WALLS -
RECOMMENDED CHUTE BLOCKS AND PRELIMINARY BAFFLE BLOCKS

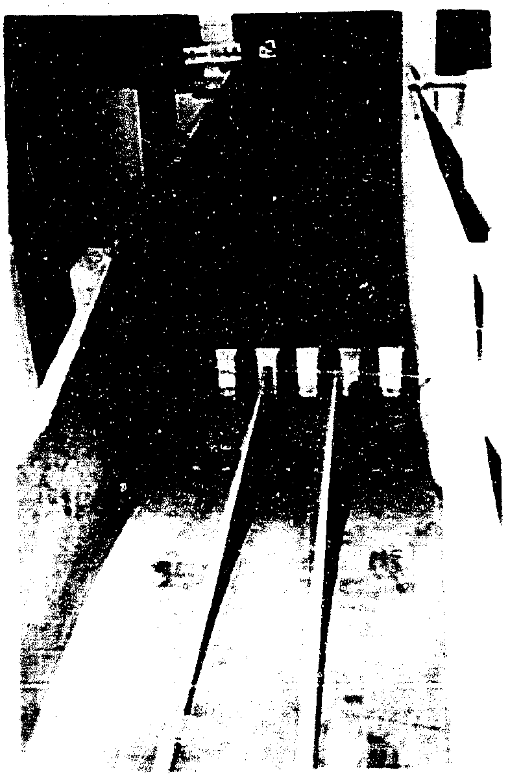


A. Exit Channel Topography before Erosion Test 18.75 Foot Dividing Walls and 4 Preliminary Baffle Blocks, Sand Bed Overlayed with Crushed Rock Representing 1/2 Cubic Foot to 1/2 Cubic Yard Riprap



B. Erosion of Right Bank and Sand Deposit Downstream of Stilling Basin Exit after 8 Hours 35 Minutes Operation of Model at Discharge 11,900 cfs. Tail-water Elevation 3466.5

ADAMINABY OUTLET WORKS
EROSION OF EXIT CHANNEL OF STILLING BASIN WITH 18.75 FOOT DIVIDING WALLS RECOMMENDED CHUTE BLOCKS AND PRELIMINARY BAFFLE BLOCKS

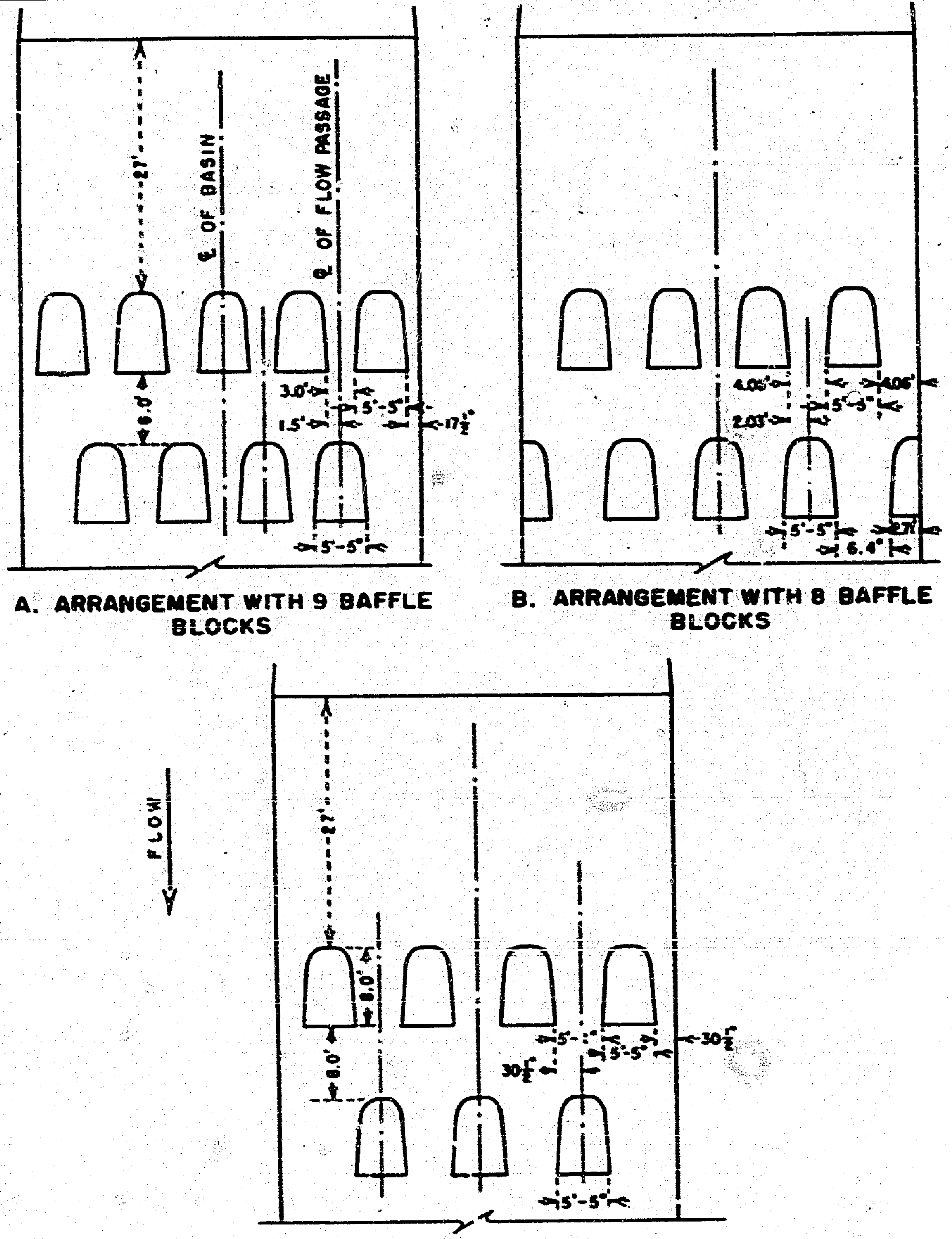


A. Five Blocks Placed 27 Feet from End of Chute

B. Streamlined Blocks Decrease Effectiveness of Stilling Basin

C. Turbulence and Waves at Exit Indicated Unsatisfactory Stilling Basin - Tail-water Elevation 3466.5

ADAMINABY OUTLET WORKS
UNSATISFACTORY BASIN OPERATION FOR FIVE RECOMMENDED BAFFLE BLOCKS PLACED 27 FEET FROM END OF CHUTE
DISCHARGE 11,900 CFS



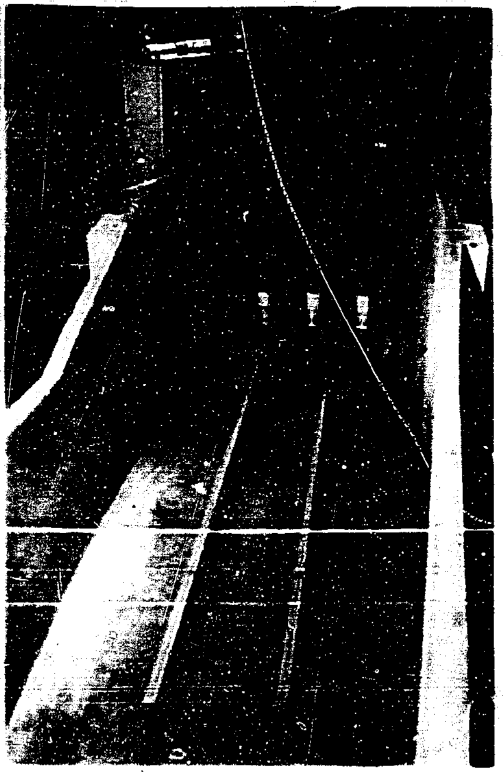
A. ARRANGEMENT WITH 9 BAFFLE BLOCKS

B. ARRANGEMENT WITH 8 BAFFLE BLOCKS

C. ARRANGEMENT WITH 7 BAFFLE BLOCKS-RECOMMENDED DESIGN AND ARRANGEMENT

ADAMINABY OUTLET WORKS

TEST ARRANGEMENTS OF RECOMMENDED DESIGN BAFFLE BLOCKS

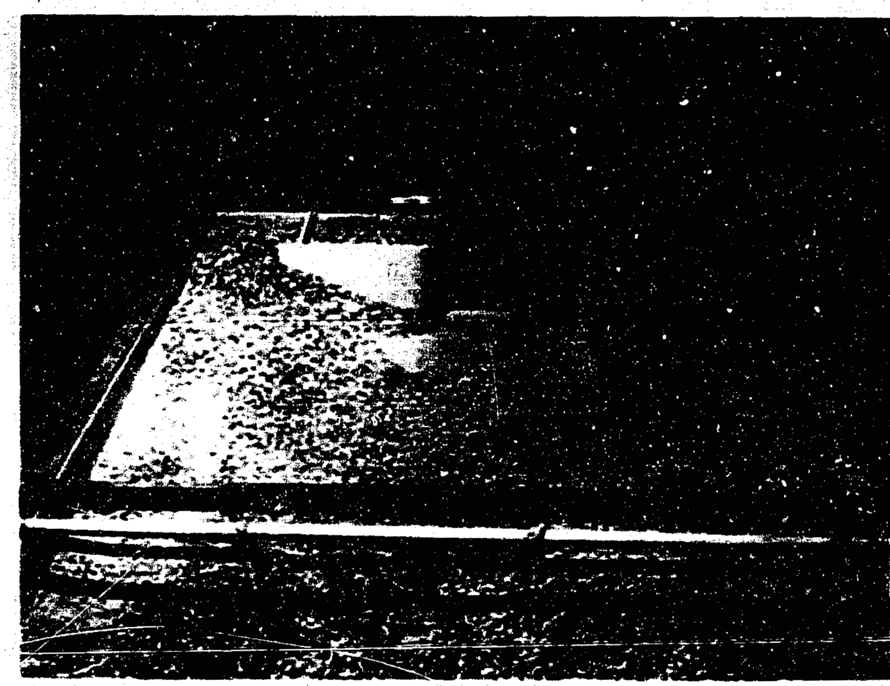


A. Recommended Stilling Basin with 18.75 Foot High Dividing Walls, 2 Rows of 8 Foot Streamlined Baffle Blocks, and 8 Foot Dentated Sill

B. Stilling Basin Action Discharge 11,900 cfs Tail-water Elevation 3466.5

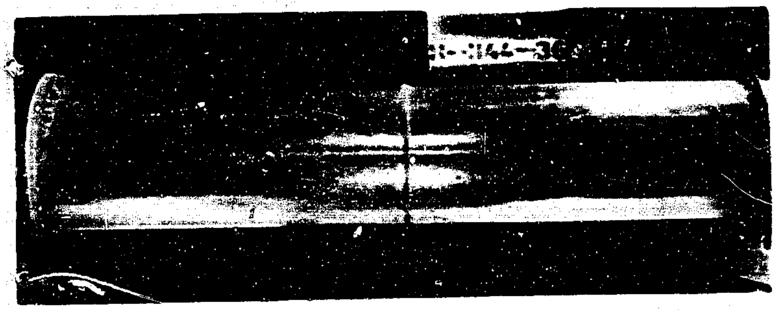
C. Wave Action at Stilling Basin Exit Discharge 11,900 cfs Tail-water Elevation 3466.5

ADAMINABY OUTLET WORKS
RECOMMENDED STILLING BASIN

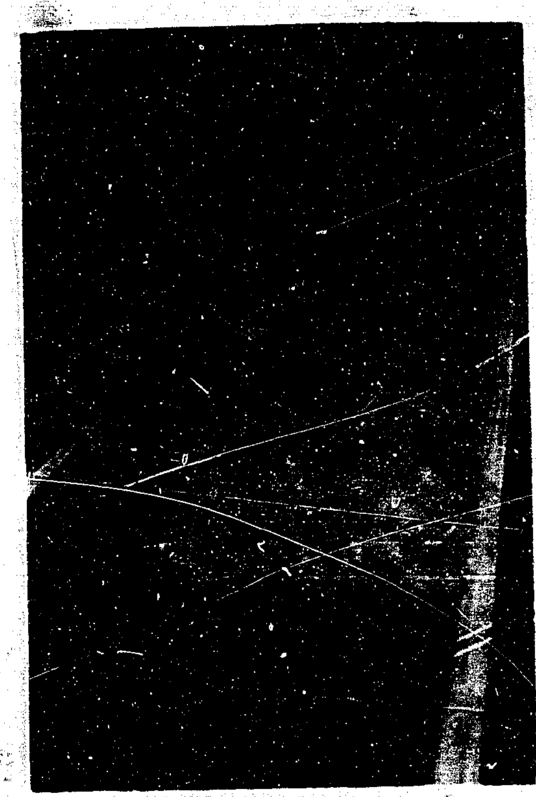


Riprap Movement and Settlement at Right Bank near End of Cut-off Wall, Sand Deposit Downstream of Stilling Basin Resulting from Erosion Test of 8 Hours 35 Minutes on Model at Discharge Representing 11,900 cfs, Tail-water Elevation 3466.5

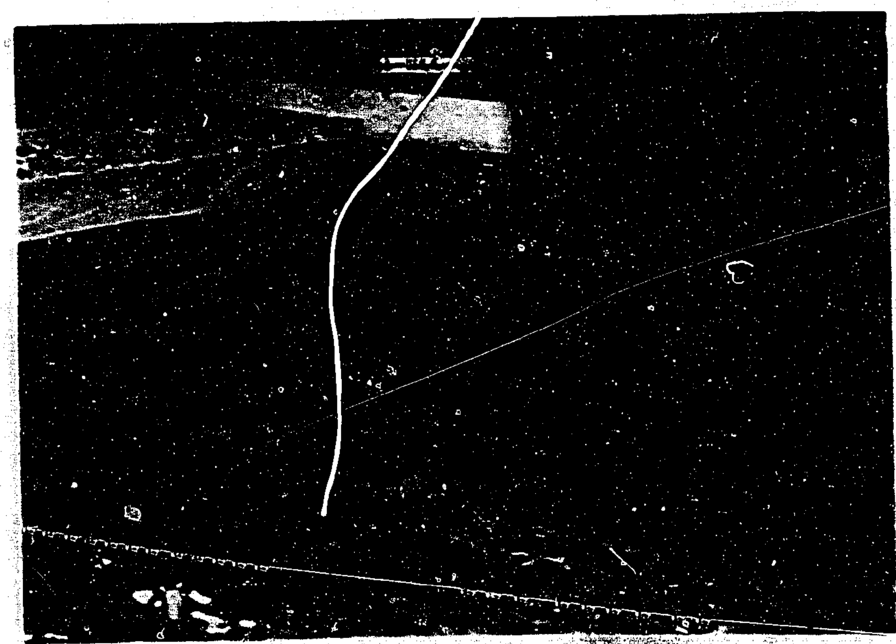
ADAMINABY OUTLET WORKS
EROSION CONDITIONS AT EXIT CHANNEL - RECOMMENDED STILLING BASIN DISCHARGE OF 11,900 CFS



A. Tunnel Flow with Regulating Gates Equally Opened 1.875 Feet - Maximum Design Head

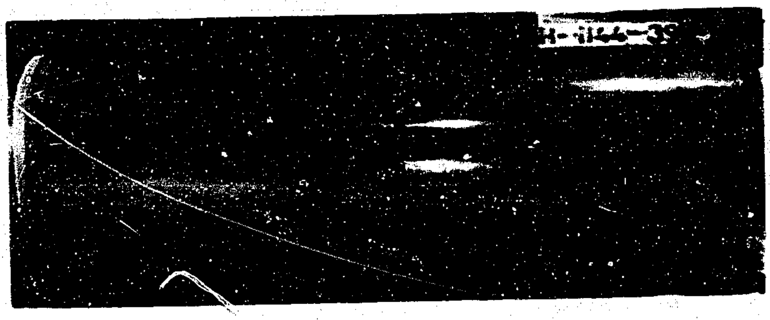


B. Chute and Stilling Basin Flow



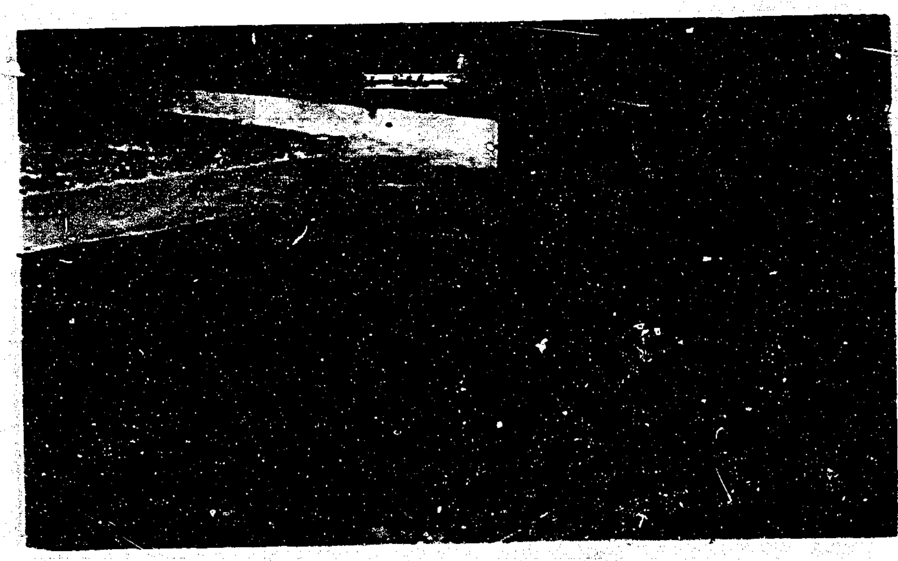
C. Exit of Stilling Basin - Tail-water Elevation 3462

ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR RECOMMENDED
OUTLET WORKS - DISCHARGE 2250 CFS



A. Tunnel Flow with Regulating Gates Equally Opened 3.75 Feet - Maximum Design Head

B. Chute and Stilling Basin Flow

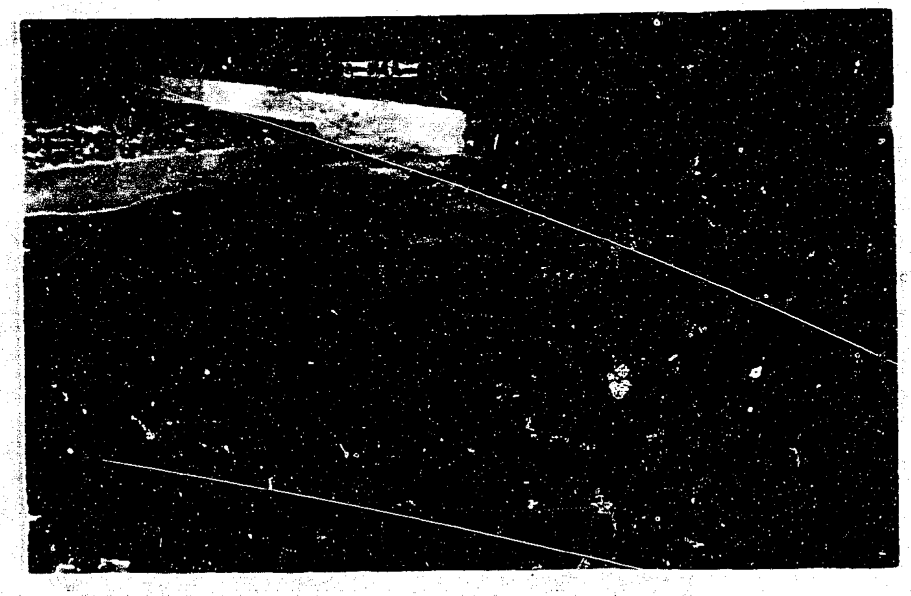


C. Exit of Stilling Basin - Tail-water Elevation 3463.2

ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR RECOMMENDED
OUTLET WORKS - DISCHARGE 4640 CFS

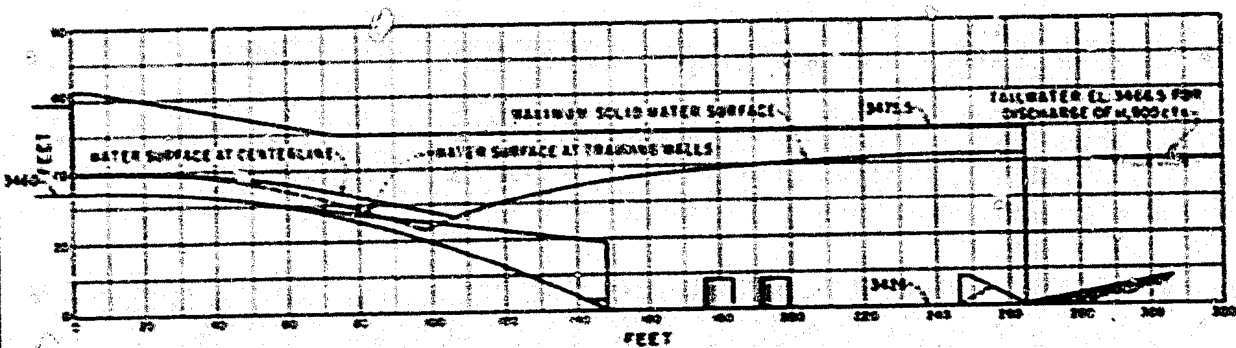
A. Tunnel Flow with Regulating Gates Equally Opened 5.625 Feet - Maximum Design Head

B. Chute and Stilling Basin Flow

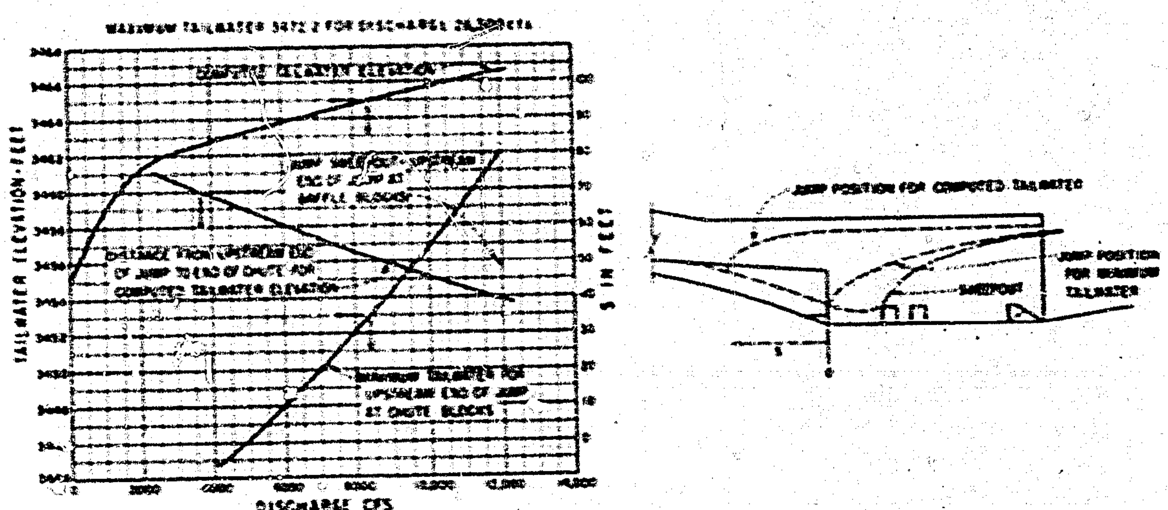


C. Turbulence at Stilling Basin Exit Tail-water Elevation 3464.5

ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR RECOMMENDED
OUTLET WORKS - DISCHARGE 7660 CFS



A. STILLING BASIN WATER SURFACE PROFILE



B. COMPUTED AND MEASURED DISCHARGE-TAILWATER RELATIONSHIP

ADAMINABY OUTLET WORKS

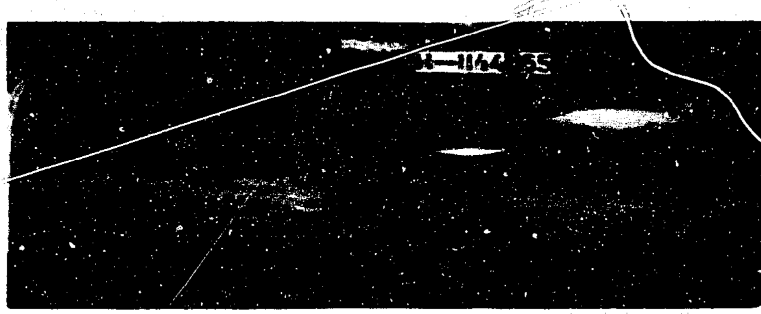
WATER SURFACE PROFILE AND JUMP POSITION

FOR RECOMMENDED STILLING BASIN

A. Tunnel Flow with the 2 Diversion Gates Equally Opened 3.5 Feet - Maximum Design Head

B. Chute and Stilling Basin Flow Conditions - Tail-water Elevation 3463.2

ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR DIVERSION
DISCHARGE OF 4700 CFS



A. Tunnel Flow with Diversion Gates Equally Opened 8.9 Feet Maximum Design Head

B. Chute and Stilling Basin Flow

C. Exit Channel Flow Conditions--Tail-water Elevation 3466.5

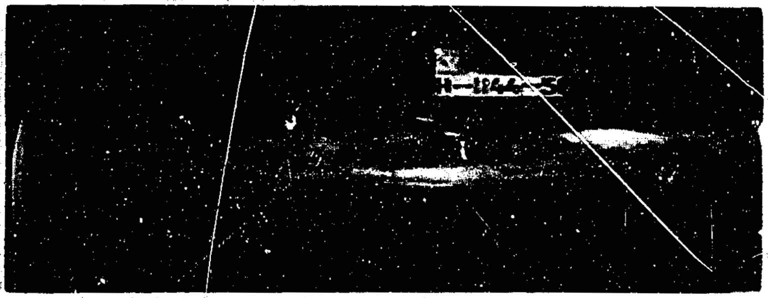
ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR A DIVERSION DISCHARGE OF 11,900 CFS

A. Tunnel Flow with Diversion Gates Equally Opened 14.2 Feet Maximum Design Head

B. Chute and Stilling Basin Flow

C. Turbulence in Exit Channel Tail-water Elevation 3469.5

ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR A DIVERSION DISCHARGE OF 20,000 CFS

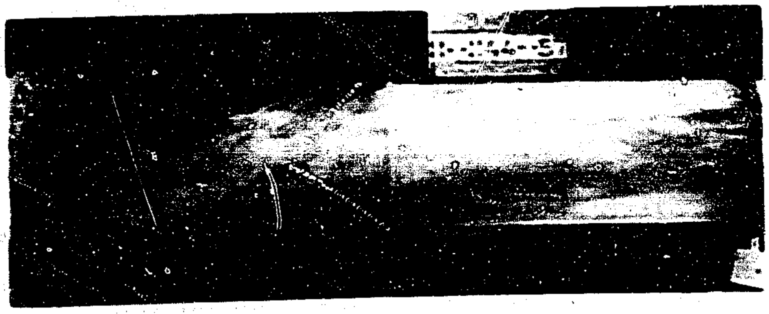


A. Tunnel Flow with Diversion Gates Fully Opened 20 Feet Maximum Design Discharge

B. Basin Sweepout at Maximum Design Discharge Tail-water Elevation 3472

C. Turbulence and Waves in Exit Channel Tail-water Elevation 3472

ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR THE DESIGN MAXIMUM
DIVERSION DISCHARGE OF 38,300 CFS

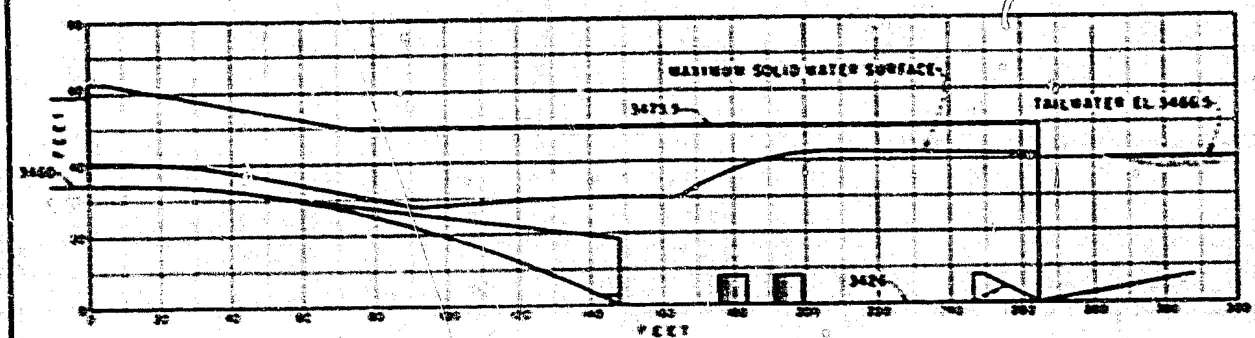


A. Left-hand Diversion Gate Fully Opened Maximum Design Head

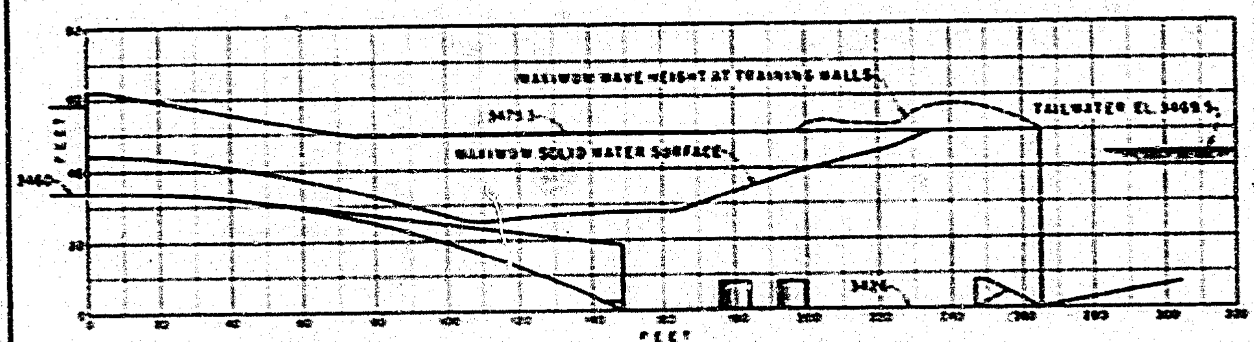
B. Water Distribution in Stilling Basin Tail-water Elevation 3468

C. Exit Channel Flow Conditions Tail-water Elevation 3468

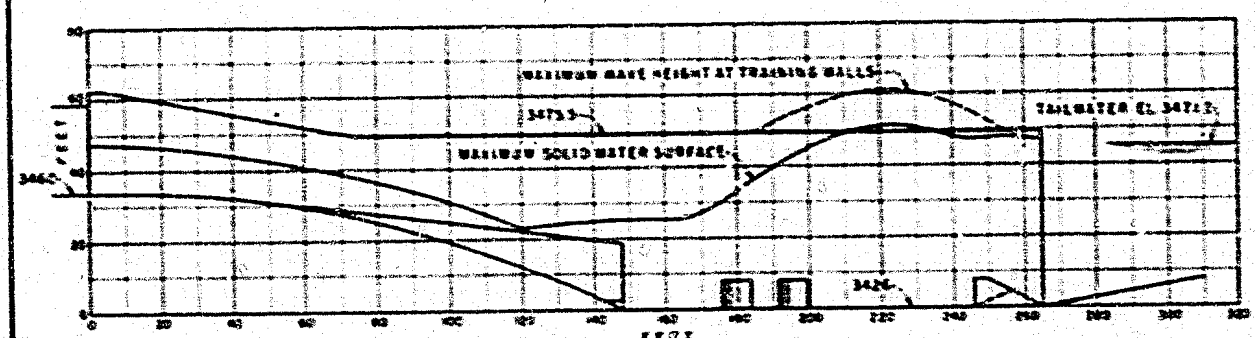
ADAMINABY OUTLET WORKS
FLOW CONDITIONS FOR A DIVERSION DISCHARGE OF
15,750 CFS FROM SINGLE GATE



A. DISCHARGE REPRESENTING 11,900 C.F.S.



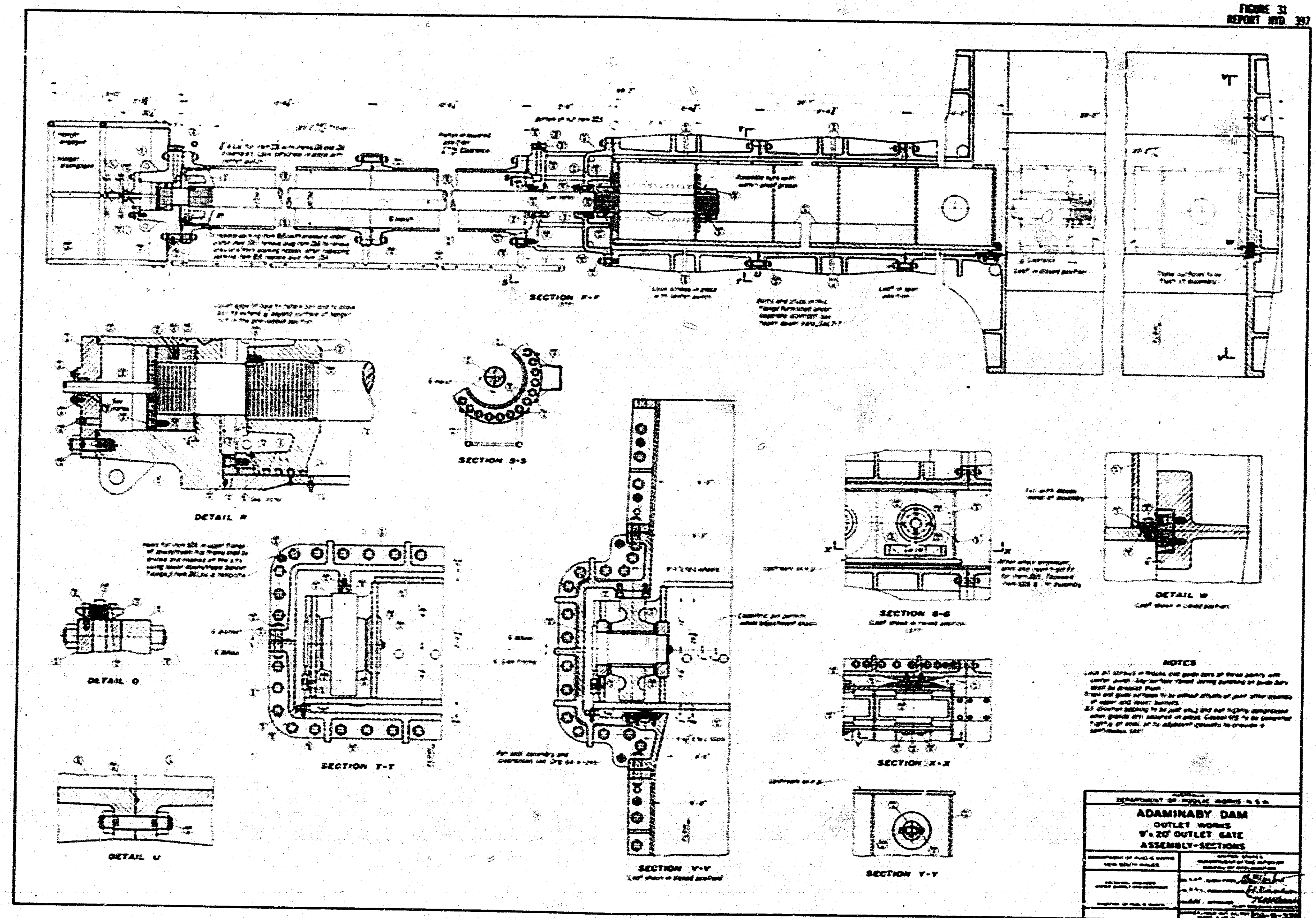
B. DISCHARGE REPRESENTING 20,000 C.F.S.

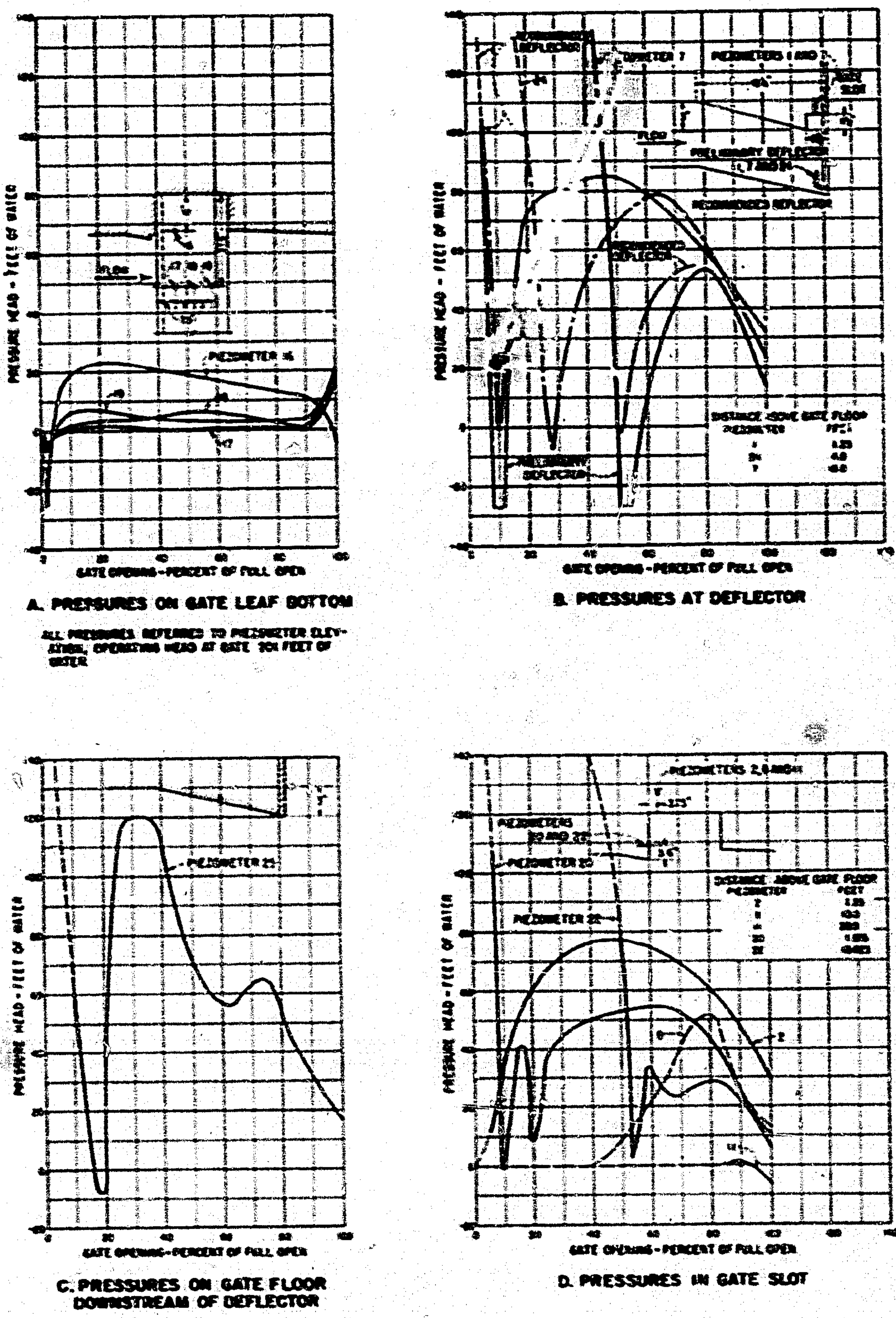


C. DISCHARGE REPRESENTING 25,000 C.F.S.

ADAMINABY OUTLET WORKS
WATER SURFACE PROFILES IN STILLING BASIN
DIVERSION OPERATION

FIGURE 31
REPORT HYD 397



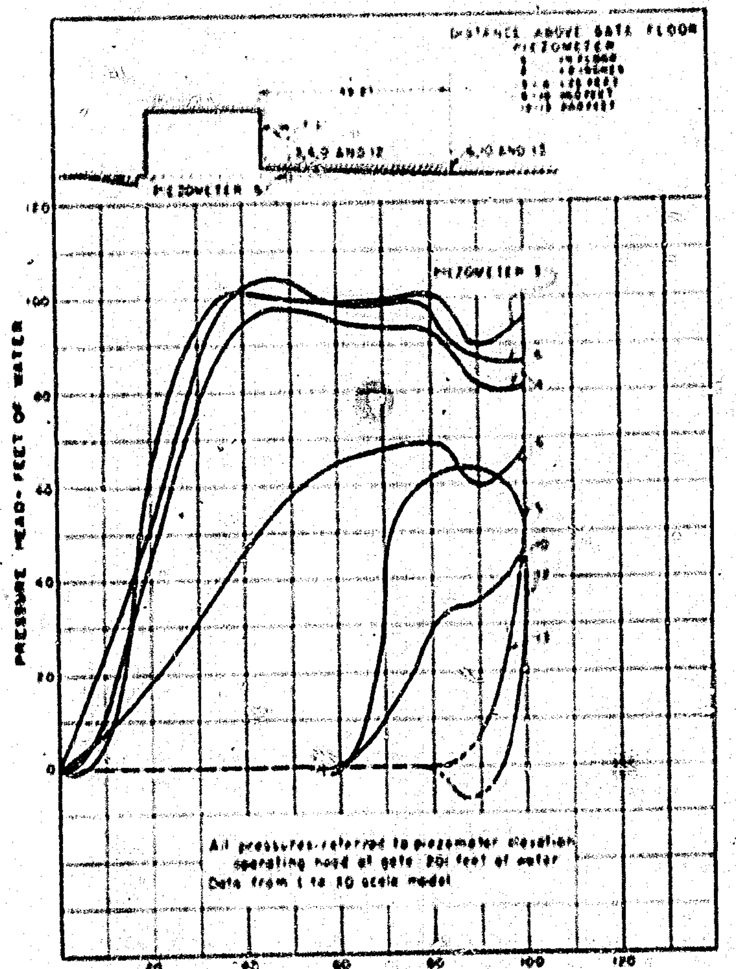


ADAMINABY OUTLET WORKS

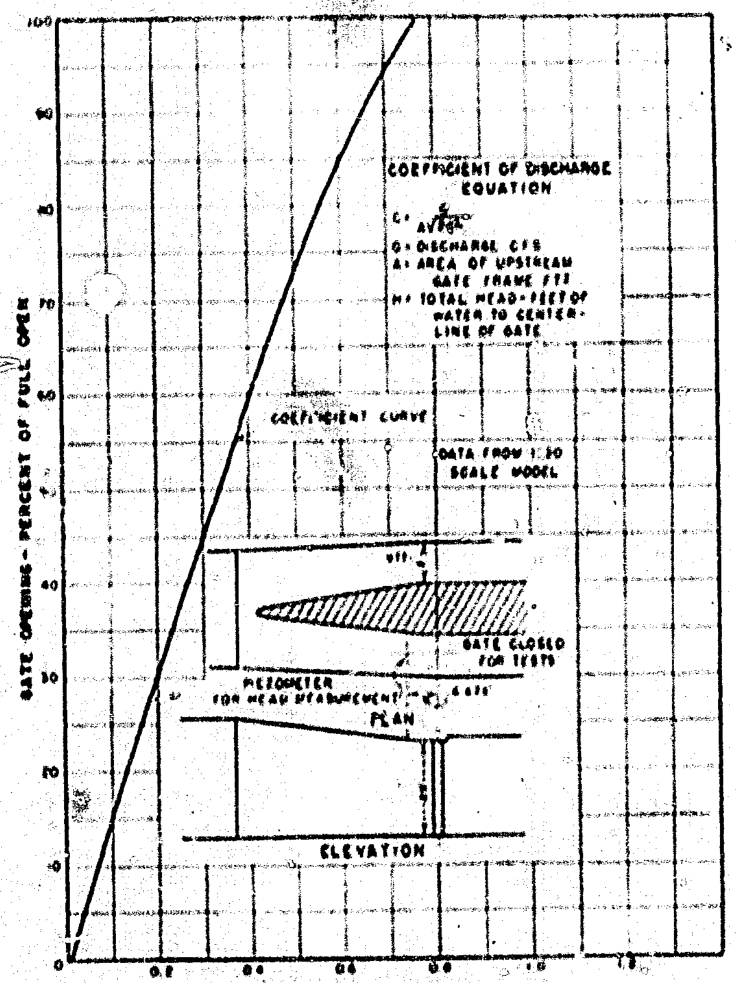
PRESSURE CURVES FOR 9 BY 20 FOOT SLIDE GATES

DATA FROM 1 TO 30 SCALE MODEL

FIGURE 53
REPORT NO. 967



A. PRESSURES DOWNSTREAM OF GATE SLOT



B. COEFFICIENT OF DISCHARGE

ADAMINABY OUTLET WORKS

PRESSURE AND COEFFICIENT OF DISCHARGE CURVES FOR 9 BY 20 FOOT SLIDE GATES